

# **Pipe Piece Family Manufacturing**

U.S. DEPARTMENT OF TRANSPORTATION

Maritime Administration

in cooperation with

Todd Pacific Shipyards Corporation

Report Documentation Page			Form Approved OMB No. 0704-0188		
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1. REPORT DATE <b>MAR 1982</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-1982 to 00-00-1982</b>	
4. TITLE AND SUBTITLE <b>Pipe Piece Family Manufacturing</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Naval Surface Warfare Center CD,Code 2230 -Design Integration Tower,9500 MacArthur Blvd Bldg 192 Room 128,Bethesda,MD,20817-5700</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES <b>57</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## FOREWORD

Typically, large numbers of pipe pieces of many varieties in mixed quantities are required for a ship. Competitive shipbuilders have proven that productivity of the overall shipbuilding process increases when pipe pieces, regardless of varieties and quantities, are produced just-in-time to support assembly workers who perform zone outfitting. In other words, a pipe shop's contribution to overall shipbuilding productivity is the only meaningful way to regard its performance.

Pipe-piece Family Manufacturing (PPFM) as described herein, is another form of Group Technology (GT) successfully applied by Ishikawajima-Harima Heavy Industries Co., Ltd. of Japan. The substance was obtained mostly from study of preparations for and operation of the very efficient pipe shop in IHI's Kure Shipyard which is manually operated and out produces automated shops elsewhere.

How well a pipe shop performs is determined by planners. Thus, necessarily is a discipline for the people who create design details and who perform material definition. PPFM includes material control in procurement and in process until pipe pieces are painted and palletized to anticipate assembly work for specific zones at specific times.

PPFM is a comprehensive methodology which simplifies the manufacture of anything required in mixed varieties and quantities, e.g., vent-duct pieces as well as pipe pieces. The planning and scheduling which has to be done is more complicated than that for traditional, less productive system-oriented methods.

No small reason for the development of PPFM and its effective application by competitive shipbuilders, is the presence of pipe-shop managers, deputy managers and field engineers who have college or equivalent educations and who have experience in other shipbuilding functions. They are, for example, able to apply statistical control for analytically and constantly improving pipe-shop methods consistent with the competitive need to constantly improve the entire shipbuilding process.

PPFM is highly organized work. Statistical control is a way to constantly improve design details and work methods. Per Dr. W.E. Deming, known as the father of productivity in Japan, "Gain is accomplished by changes in the system effected by management helping people to work smarter, not harder."

## ACKNOWLEDGEMENTS

L.D. Chirillo Associates, Bellevue, Washington produced this book for Todd Pacific Shipyards Corporation, Los Angeles Division.

The book was developed in three stages. M. Kasama, International Division, Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) of Japan, compiled most of the substance and performed the difficult translation into English. C.S. Jonson, Science Applications, Inc., La Jolla, California, developed the draft, in the context of the IHI submittal and a literature search of Group Technology, which was used to solicit U.S. shipbuilders' comments. The work was next significantly edited and supplemented by L.D. Chirillo assisted by R.D. Chirillo.

Appreciation is particularly expressed to Y. Murota, Pipe-shop Manager in IHI's Kure Shipyard and truly a shipbuilding engineer/manager, for conveying an understanding of his responsibilities. Appreciation is expressed for comments and assistance received from a number of U.S. shipbuilders. Appreciation is also expressed to Y. Mikami and Y. Ichinose of IHI Marine Technology and to T. Lamoureux, L. Willets, D. Arnold and B. Coralles of Todd's Los Angeles Division, who furnished essential support.

This book is an end product of one of the many projects managed and cost shared by Todd for the National Shipbuilding Research Program. The Program is a cooperative effort by the Maritime Administration's Office of Advanced-Ship Development and the U.S. shipbuilding industry. The objective, described by the Ship Production Committee of the Society of Naval Architects and Marine Engineers, is to improve productivity.

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#### Appendix A - Problem Area Subdivision

- pipe-piece Family Classifications
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- Examples of PPFM codes
- Decision Logic Table for PPFM Codes

#### Appendix B - Pipe-piece Fabrication Flow

#### Appendix C- Work Load Schedules

#### Appendix D - Subcontracting Expense Calculation

- Operations Control Lists



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This book is dedicated to the memory of  
a shipbuilder  
from Vancouver, British Columbia

Leslie Coward

July 19, 1925 — March 18, 1982



### 1.1 Principles

Generally, fabrication of components for ships is planned by addressing ship-systems separately and then considering each component in a system to be unique. Thus, an interim product such as a pipe piece is separately planned and scheduled. As just the engine room of a 20,000 deadweight-ton ship contains approximately 3,500 pipe-pieces, custom manufacturing all of them involves large volumes of data and inherently poor productivity.

Group Technology (GT), a management philosophy, features organizing work so that common solutions are applied to common problems. It is the recognized means for acquiring the benefits of mass production for high variety, mixed quantity products. By identifying similarities in manufacturing problems, different products are grouped for similar processing. A variety of products so grouped to match a set of solutions is called a *family*. Hence, GT when applied to fabrication work is called *Family Manufacturing*.

Ideally, the various machines needed to fabricate products of a particular family should themselves be grouped as a *production line*. Thus, instead of operation-by-operation planning as needed for custom manufacturing, all operations that could be performed by a group of machines are regarded as a preplanned single entity. This is called *process categorization*. Applied in a pipe shop it is called *Pipe-piece Family Manufacturing (PPFM)*.

Normally, the total numbers of pipe pieces for each process categorization do not justify redundant equipment installations that would permit every production line to be independently operated. Thus, preplanning for two or more families anticipates that for some operations the production lines merge so that the use of a single machine, e.g., a pipe bender, is fully exploited.

With facilities so organized and operations so preplanned, the average duration for fabrication of a pipe piece of a particular family can be readily determined. Analysis of work required at each stage and summation of the times needed per stage and between stages is the basis for determining the number of pipe pieces that can be fabricated in a flow lane in a given period. This knowledge permits control by lot for a given period, usually a week, which is very effective.

PPFM is a highly advanced production logic. Competitive shipbuilders recognize it as the prerequisite for pipe shop facilities planning. As work flows can be virtual, even where facilities were left unchanged, PPFM simplified planning enhanced material and production controls and significantly improved productivity.

Determination of families necessarily considers both design and manufacturing attributes. Among the former are size material type and shape whereas the latter includes:

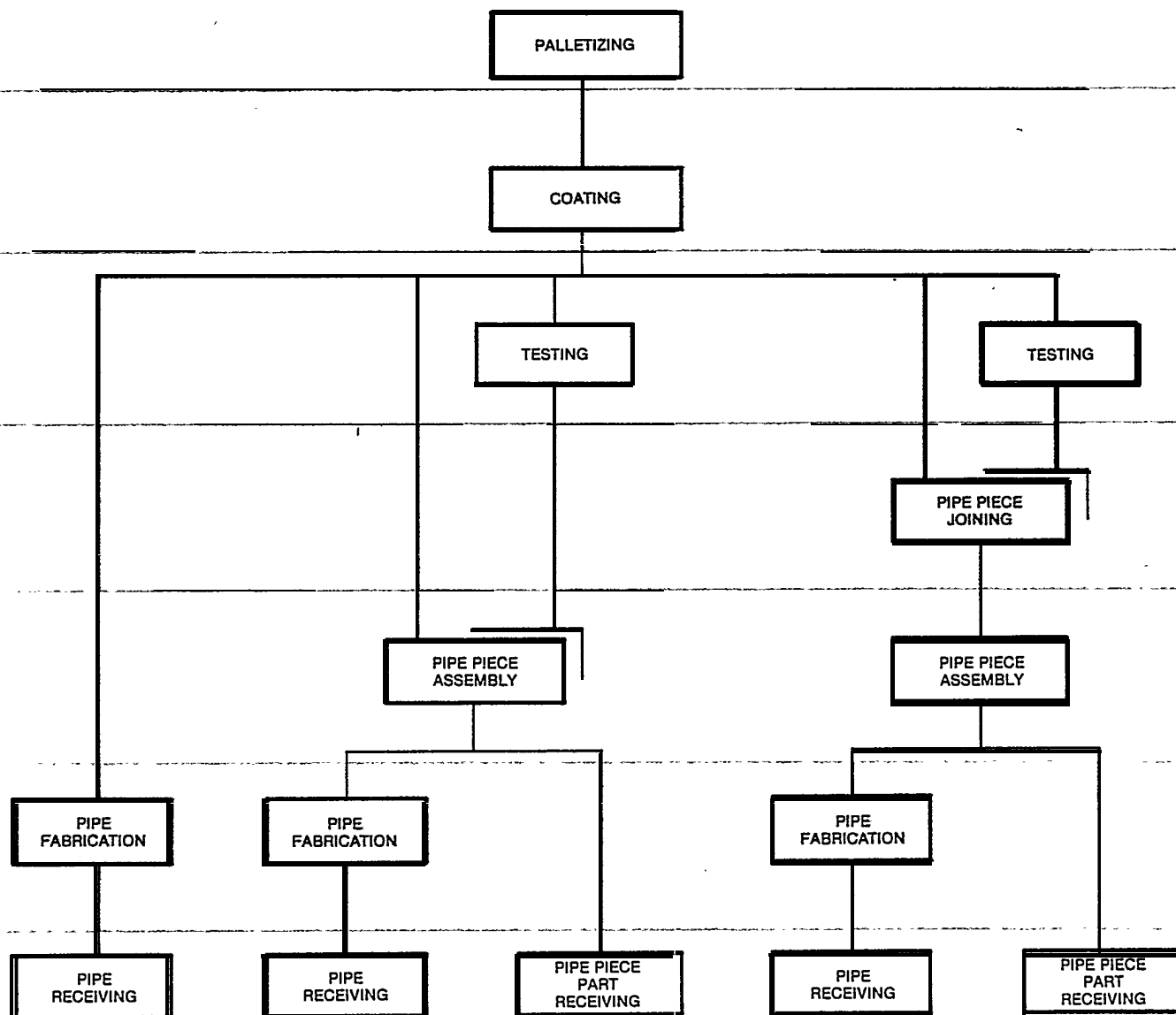
- the management control system,
- capacities of both the pipe shop and regularly engaged subcontractors, and
- fabrication equipment and its layout.

In shipbuilding, a pipe shop's work load is dictated by requirements to support outfitting with high variety, mixed quantity pipe pieces in a timely manner. However, traditional shop managers subordinate this objective by batch manufacturing identical or nearly identical components as a means for apparently improving productivity. This limited point-of-view causes a significant number of components to be produced well in advance of outfit assembly requirements. Other real costs are ignored, such as:

- the cost of money for earlier than necessary investments
- direct and indirect costs associated with additional warehousing and material control problems, and
- disruption costs due to forcing design, material definition and material procurement sequences that do not match an ideal outfit assembly sequence.

This limited viewpoint often causes shop resources to be preoccupied with such batches thus increasing the potential for further disrupting assembly operations.

GT also features batch manufacturing but employs different principles. It features grouping products by problem areas to create pseudo-batches which are very effective for bringing the benefits of mass production to internal pipe-shop operations. At the same time, GT permits the production of various types of pipe pieces as required for zone outfitting. The results are gains in both pipe-piece fabrication and outfit assembly productivity.



*Figure 1-1: Typical Manufacturing Levels for Pipe Piece Family Manufacturing (PPFM). Note that Coating and Palletizing are each a manufacturing level, i.e., each pipe piece is not complete until it is coated and grouped with other required pipe pieces in order to support zone outfitting.*

PLNG LEVEL	MFG LEVEL	PRODUCT ASPECTS					CODES		
		ZONE	AREA			STAGE	ZONE	AREA	STAG
1	7	PALLET	DECK INCLUDING ELECTRICAL	ACCOMMODATION INCLUDING ELECTRICAL	MACHINERY INCLUDING ELECTRICAL	PALLETIZING	PALLET CODE	SHOP NO.	SHOP NO.
2	6	PIPE	COATING PROCESS			COATING	COATING CODE	COATING CODE	COATING CODE
						PICKLING			
3	5		TEST PROCESS			TESTING	PIPE PIECE NO.	PIPE PIECE MANUFACTURING LANE CODE	PIPE PIECE MANUFACTURING LANE CODE
						NIL			
4	4	PIPE	NIL	PIPE MATERIAL X-RAY OR NIL/BORE/STRAIGHT OR BENT/LENGTH		FINISHING	PIPE PIECE NO./MAIN OR BRANCH SIGN	PIPE PIECE MANUFACTURING LANE CODE	PIPE PIECE MANUFACTURING LANE CODE
						WELDING			
						JOINING			
						MARKING & CUTTING			
5	3	PIPE	NIL	PIPE MATERIAL/ X-RAY OR NIL/ MAIN OR BRANCH/ BORE/STRAIGHT OR BENT/LENGTH		BENDING ON PIPE PIECE	PIPE PIECE NO./MAIN OR BRANCH SIGN	PIPE PIECE MANUFACTURING LANE CODE	PIPE PIECE MANUFACTURING LANE CODE
						FINISHING			
						WELDING			
						ASSEMBLY			
6	2	PIPE	NIL	PIPE MATERIAL/PIPE MAIN OR BRANCH/BORE		CUT PIPE JOINING	PIPE PIECE NO./MAIN OR BRANCH SIGN	PIPE PIECE MANUFACTURING LANE CODE	PIPE PIECE MANUFACTURING LANE CODE
						MACHINING			
						BENDING ON CUT PIPE			
						MARKING & CUTTING			
7	1	MATERIAL	PIPE	PIPE PIECE PART		RECEIVING	MATERIAL CODE	MATERIAL CODE	NIL

figure 1-2: Typical Classifications of Product Aspects for Pipe piece Family Manufacturing (PPFM). System is absent and zone has virtually no significance until palletizing. Pipe shop organization is based only on problem area and stage except for palletizing. Typical problem area subdivisions are presented in Appendix A.

The goal for selecting families and planning their routes is to utilize production-line principles. A production line frees workers from having to plan a work sequence for each pipe piece. Instead, they concentrate on executing normal work processes. Because of this expertise, workers are better able to participate in constant evaluation and improvement of work methods. However, a production line cannot free workers from unnecessary, repetitive planning chores unless:

- fabrication problems are anticipated by people who perform design and material definition, and
- shop planning and scheduling is consistent with production-line principles.

The production-line principles are:

- standardization of processes,
- simplification and specialization of operations,
- establishment of fixed work stations,
- moving work pieces along a fixed route, and
- designating positions for workers or teams of workers.

Figure 1-1 illustrates typical manufacturing levels and basic logic used by a competitive shipbuilder to organize production lines and work flows for both manual and automated operations. *Coating* and *palleting* are each included as a distinct manufacturing level necessary for supporting zone outfitting.

Figure 1-2 shows associated classifications consistent with a product-oriented work breakdown. The product aspects described are noteworthy. *System* is absent and *zone* has virtually no significance until palletizing. As long as each pipe piece is produced by its scheduled pallet date, the organization of production lines and work flows are based only on problem area and *stage*. In other words, pipe-shop operations are idealized without being encumbered by having to separate pipe pieces per ship or per system.

Figures 1-1 and 1-2 are examples of the logic necessary for any mix of pipe-piece requirements to establish

- pipe-piece families,
- production lines, and
- work flows which optimize use of facilities.

## 1.2 Design

As shown in Figure 1-3, modern shipbuilding technology requires that design be truly an aspect of planning. As a design effort progresses, planning requirements change formats in order to:

- describe a ship as a system,
- address individual systems,
- provide an interrelationship between systems and zones,
- produce design details organized by relatively small increments for assembly work classified by zone, problem area and stage, and finally,
- subdivide the latter into work instructions for prerequisite fabrication work.

1.2.1 *Functional design* is the first stage for planning fabrication activities. For pipe-piece fabrication several key elements are determined:

- diameter,
- material,
- service pressure,
- testing requirements by system, and
- surface treatment.

Using standards as much as possible, functional designers define *all* material requirements for each system diagrammatic. The material so identified is also organized by relatively large zones sequenced in the order that a ship will be erected. The format for such integrated information is called MLS - Material List by (ship's functional) System (by purchasing zone).

MLS indicate what materials are required and approximately where and when they are required. Although portions are necessarily estimates, MLS are practical enough for fast start-up of material ordering before detail design commences. Early resolution of difficult material procurements is essential for productive PPFM.

1.2.2 *Transition design* addresses the shift from system to zone orientation. As shown in Figure 1-4, system diagrammatic are quickly routed, often freehand, on machinery arrangement drawings. These serve as analytical tools for examination of such aspects as:

- access for safe and efficient equipment operation,
- relative positions of piping and hull structure,
- maximum utilization of straight pipe,
- pipes grouped in parallel to facilitate assembly,
- access for outfitting on-unit, on-block and on-board, and
- inclusion of all systems.

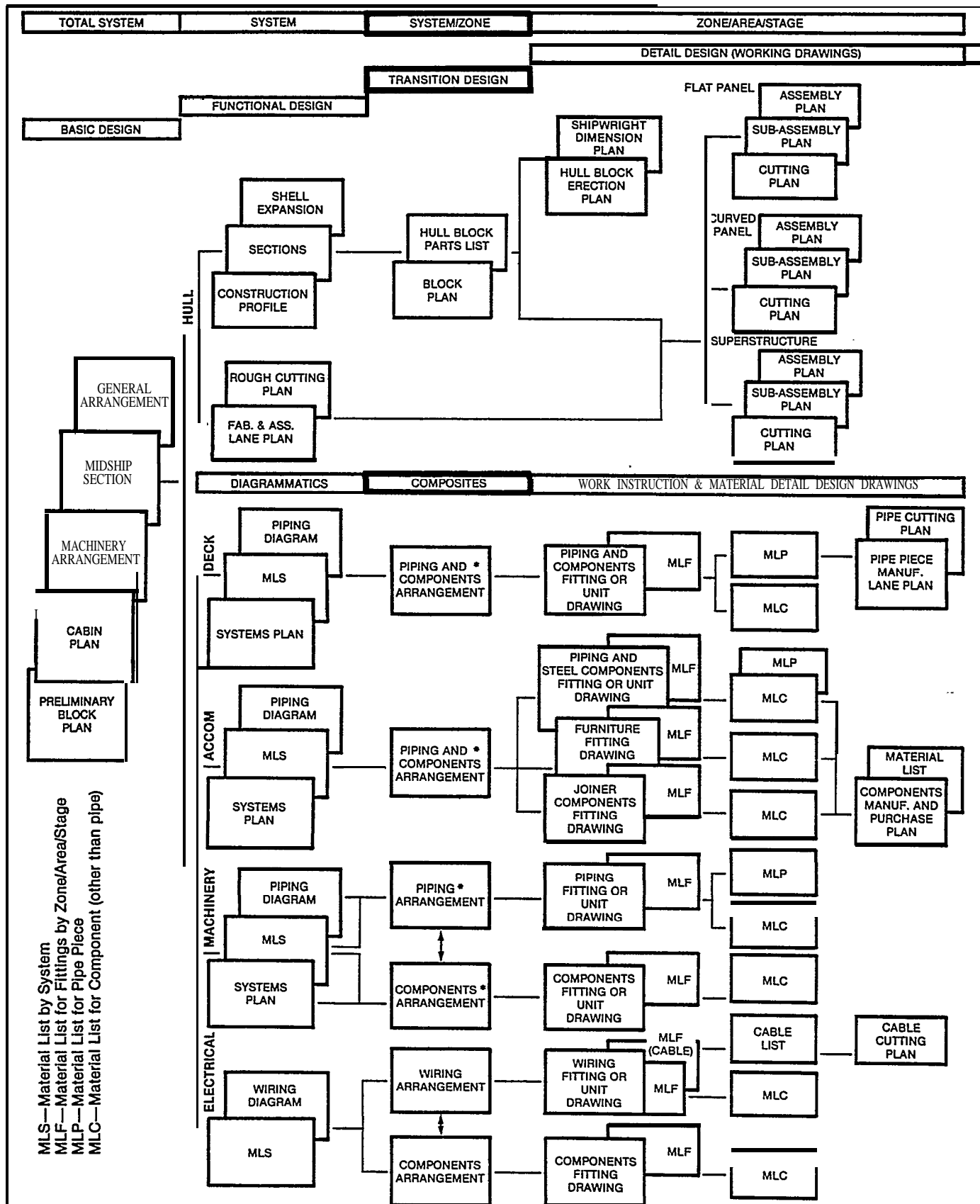


Figure 1-3: Product-oriented Design Process. Transition Design introduces zones and interrelations with systems. The items marked "\*" we for quickly conveying arrangements and system/zone relationships to detail designers. The latter refine arrangements and incorporate stage designations as they prepare work instruction and material detail-design drawings.

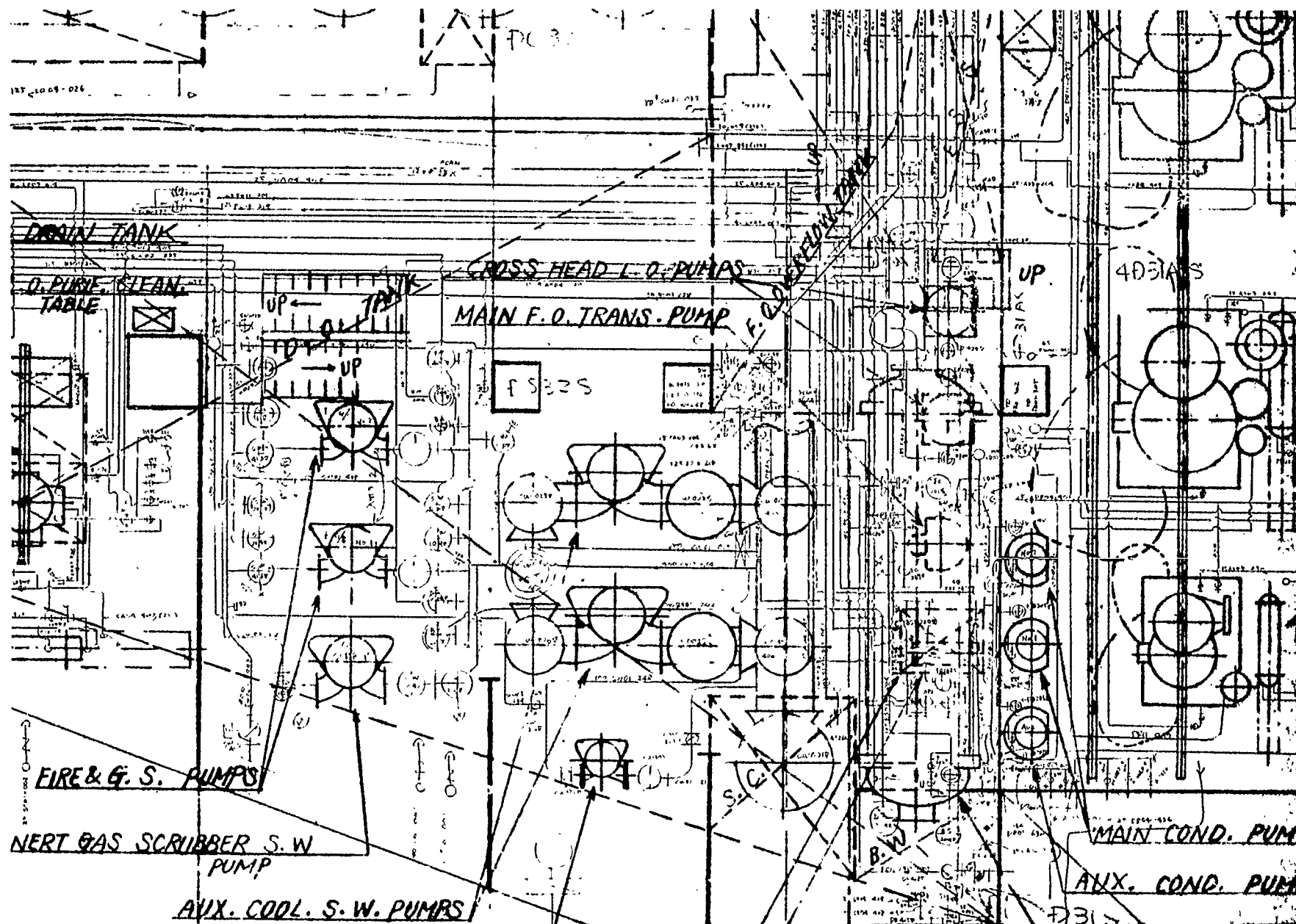


Figure 1-4: Outfit Transition Design. In order to quickly relate systems and zones, machinery-space arrangement specialists arrange diagrammatics together. Relative positions of distributive systems, including fittings such as valves, are frequently adapted from a file of design modules and/or anticipate work packages classified by zone/problem area/stage.

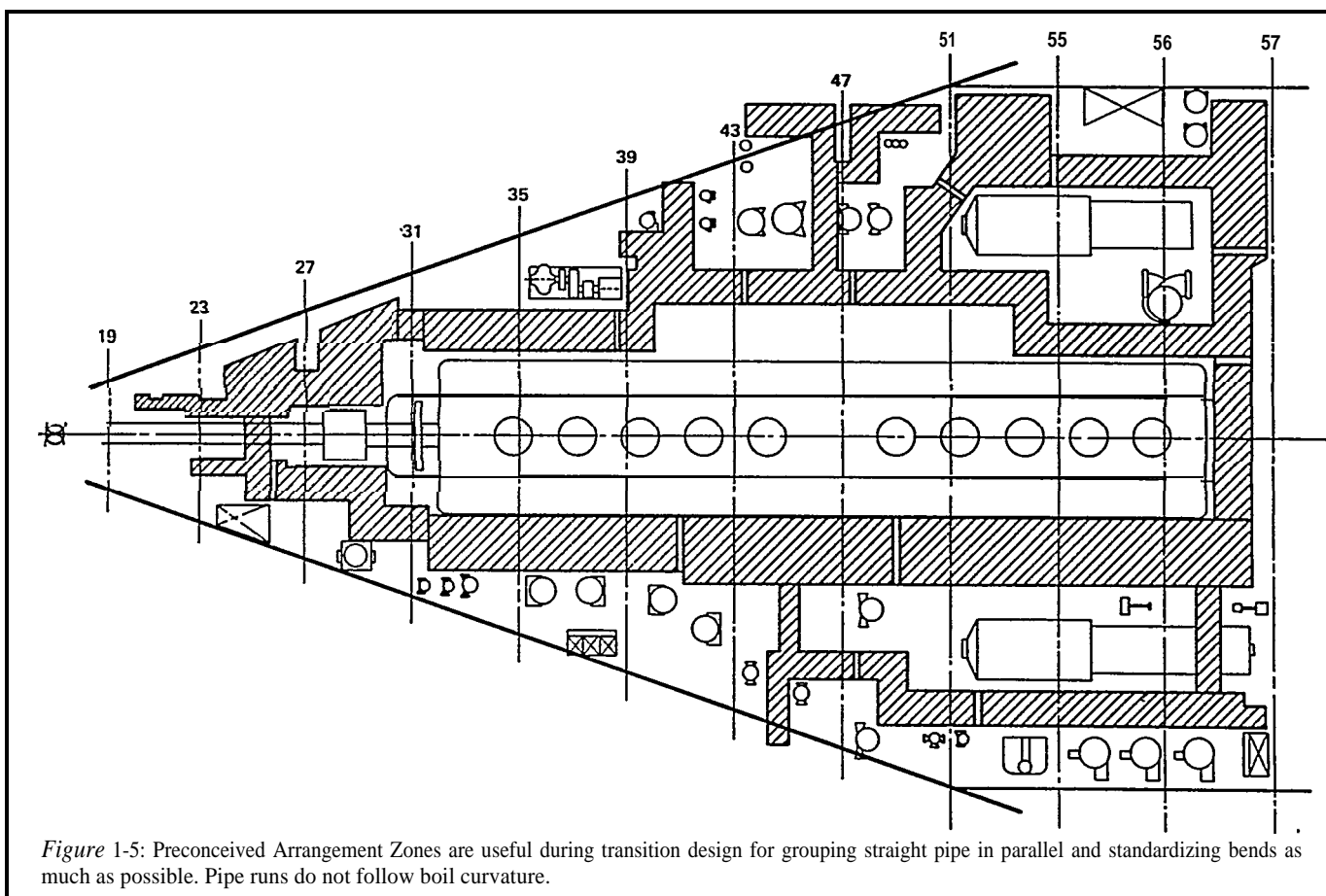


Figure 1-5: Preconceived Arrangement Zones are useful during transition design for grouping straight pipe in parallel and standardizing bends as much as possible. Pipe runs do not follow hull curvature.

Transition analysis requires the most experienced designers because it determines outfitting costs. Further, it impacts on maintenance costs during a ship's lifetime. During transition analysis, designers incorporate straight pipe in parallel as much as possible in pre-conceived *arrangement zones*.<sup>2</sup> Clearly, a designer's systematic incorporation of straight and parallel pipe-runs greatly impacts on the productivity of both pipe-piece fabrication and outfit-unit assembly see Figure 1-5.

Typical goals for transition designers are

- equal distribution of pipe-runs to Port and starboard.
- equal distribution of pipe-runs on-all levels,
- minimum total pipe length in order to minimize pressure drops and material costs,
- valves on operating sides of machinery,
- branches on machinery sides of mains,
- straight pipe-runs beneath passages around the main engine and auxiliary machinery,
- straight pipe-runs incorporating only 45° and 90° bends, and
- preliminary arrangement of all diagrammatic for pipe 15 millimeters diameter and larger.

Usually, the output of transition design features plan view only. Elevations are limited to complicated arrangements. Transition design produces a master which facilitates control when work-instruction (detail) design is apportioned to number of people.

1.2.3 *Work-instruction design* at first produces a composite, as illustrated in Figure 1-6, which incorporates detail such as exact delineation of pipe pieces and their orientation to each other and to other fittings. Alternative methods for creating and maintaining a detailed composite design are:

- scale models, and
- computer-operated interactive graphics.

A common inefficiency, often imposed by owners and sometimes by shipbuilders themselves, is the use of more than one of the above methods for simultaneously maintaining the same composite design. Some compound this inefficiency by further requiring unneeded system-arrangement drawings. As a result, design manhours are unnecessarily consumed and more seriously, detail-design progress is impeded. Progress is especially retarded by attempts to coordinate use of two methods for the same composite, e.g., drawings plus a scale model.

<sup>2</sup> Arrangement zones are described in Chapter 3.0, "Outfit Planning - December 1979" by C.S. JonSon and L.D. Chirillo for the National Shipbuilding Research Program.

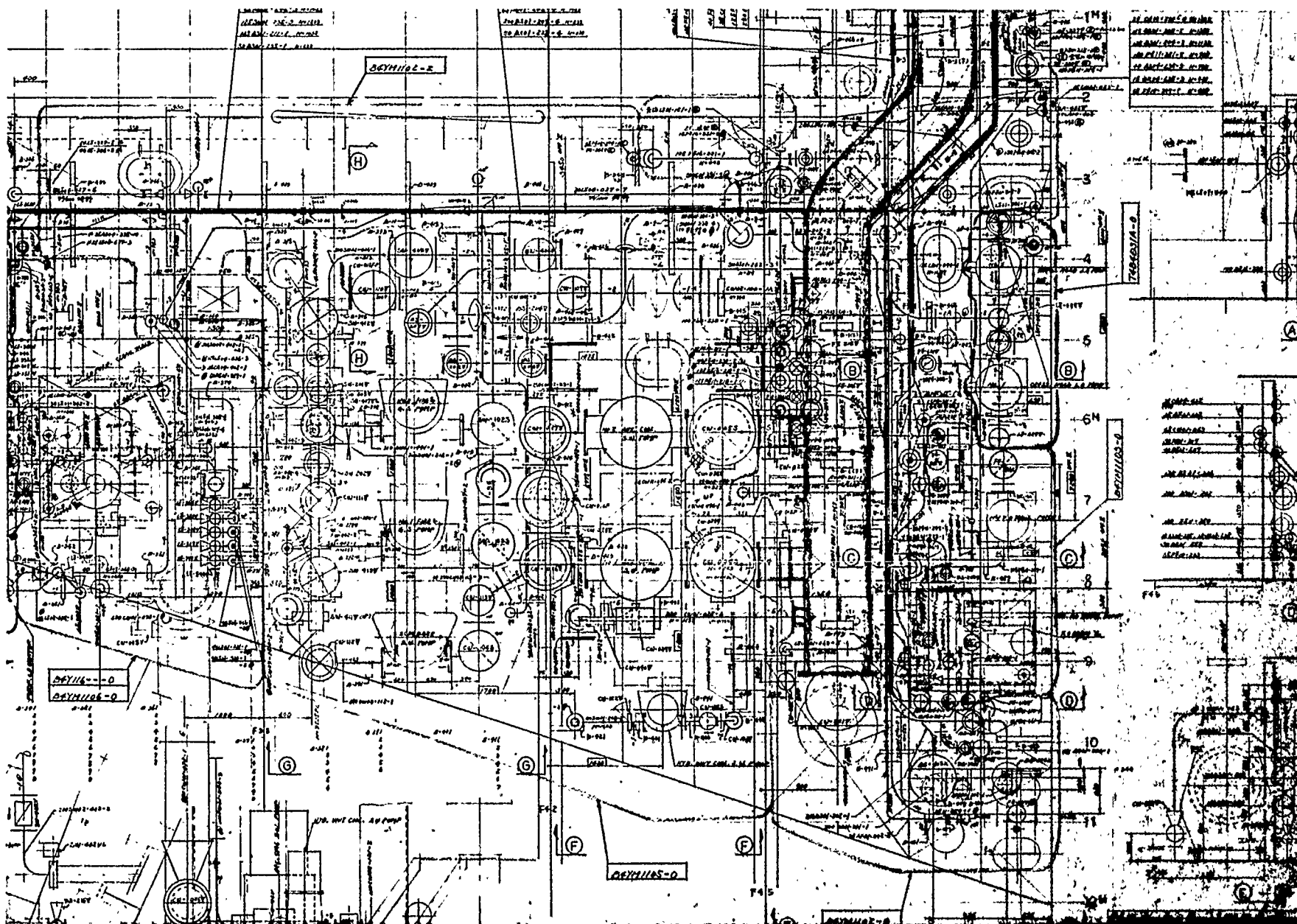


Figure 1-6: Detail Fitting Arrangement. This composite drawing is marked to show zone demarcations. Zone/problem area/stage classifications are coded in work package numbers such as B4YM1105-0. Generally, only plan views with single-line representations of pipe pieces are sufficient. Elevations and double-line representations are limited to complicated regions. Pipe pieces are defined by families and associated with work packages on composites, i.e., before time is taken to produce pipe-fabrication details.



Detailed composites of any kind are required by shipbuilders only for:

- material definition,
- orientation of fittings relative to each other for assembly work instructions, and
- details sufficient for fabrication work instructions.

As practical methods exist for readily digitizing from both composite drawings and scale models, computers can supplement any technique used for *creating* a composite design.<sup>3</sup> Computers are already used to produce pipe-piece fabrication instructions, including their material lists, in various formats, e.g.:

- orthographic (Figure 1-7),
- isometric, and
- Z symbolic (Figure 1-8).

Symbolic pipe-piece details, now widely accepted, are preferred because they are digitized. They are readily combined and computer processed together with pertinent production control data, e.g., pipe-piece family identifiers, assembly-work package numbers and material lists. Start fabrication and palletizing dates are incorporated so that a single portion of a printout contains all needed planning and scheduling data for each pipe piece. Obviously, necessary revisions are easier to control when all required information appears on one document.

When work instructions are less geometric and more numeric, the necessity for accuracy is reduced to essentials. Even when computers are used, more wherewithal is needed to produce geometrically accurate sketches. On geometrical sketches everything must be accurate, whereas on numerical presentations only major points must be accurate.<sup>4</sup>

Although digital notations are more effective and more naturally processed by computers, some shipbuilders continue to apply computer-aided design tools to produce conventional pipe-piece sketches and their material lists. Some are computer-producing sketches and employing independent material control programs. There is inherent duplication of effort and significantly increased opportunity for human error. Producing pipe-piece *sketches* by computer can be justified if it is an interim measure pending

- training workers to interpret digitized notations, or
- adoption of numerically-controlled fabrication methods.

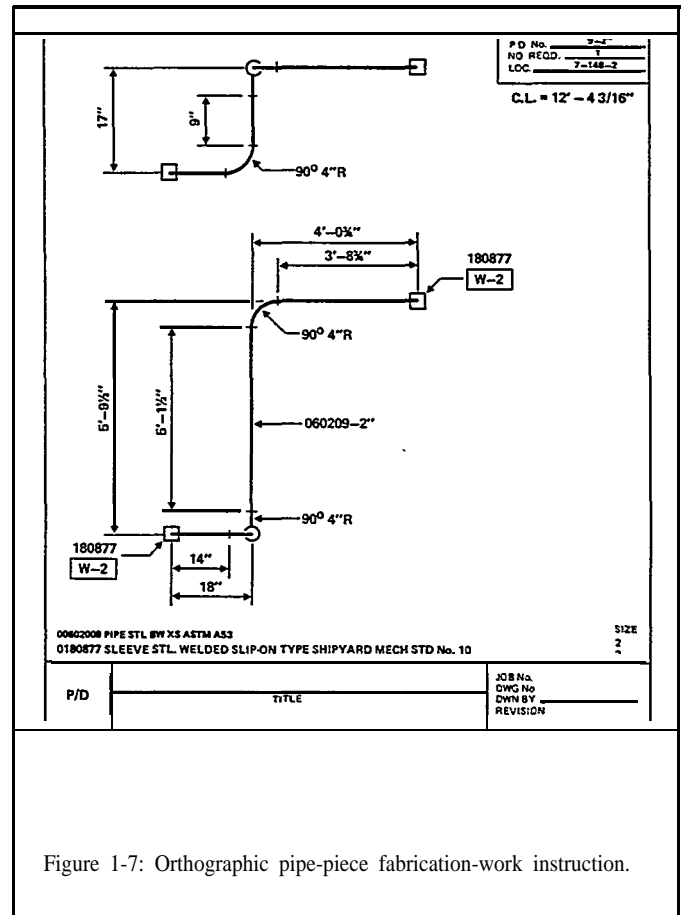


Figure 1-7: Orthographic pipe-piece fabrication-work instruction.

Otherwise, the computer is being used to produce more accurately and more quickly, archaic notions. This is a paradox.

Regardless of the degree of automation, designers must provide the following data as appropriate for each pipe-piece work instruction:

- required length of raw pipe,
- required other materials, e.g., flange, elbow, tee, etc.,
- angle and dimensions for bends,
- margins required for bender grip and flange fitting,
- angle between main and branch,

<sup>3</sup> "Photogrammetric Dimensioning of Ships' Engine-room Models-March 1981" by J.F. Kenefick and L.D. Chirillo for the National Shipbuilding Research Program.

<sup>4</sup> Attributed to K. Ogawa, IHI International Division by C.J. Starkenburg, Avondale Shipyards, Inc., in the presentation "Implementing IHI Technology at Avordale" to the REAPS Technical- Symposium 14-16 October 1980, Philadelphia, Pennsylvania.

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* TP.0(A-D)- TUBO = 60.3 X 3.91 ASTM A 106 GRADE B - L = 1576 MM
WIRTZ A C.N.
-----AR-----AP-----DX-----DY-----DZ-----ACCESSORI-----
B .0 45.0 AB 940. 0. 0. FLANGIA 2' N 409.10
C 100.0 45.0 AC 250. -260. 0.
D .0 .0 CD 300. 0. 0. FLANGIA 2' N 409.10
-----TOT 1500. -260. 0.-----
DIAGONALI : A-B= 940/B-C= 367/C-D= 300/

* BR.1(E-F)- TUBO = 60.3 X 3.91 ASTM A 106 GRADE B - L = 195 MM
TUBO RETTO / A-E = 450 MM / ANG.F-E-B = 90. GRADI
-----AR-----AP-----DX-----DY-----DZ-----ACCESSORI-----
F .0 .0 EF 0. 200. 0. FLANGIA 2' N 409.10
-----
DIAGONALI : E-F= 200/

```

Figure 1-8: Symbolic pipe-piece fabrication-work instructions are natural for cost-effective computer processing.

- flange orientation,
- branch shape,
- branch position,
- material quantities for a complete MLP,
- $\bar{Z}$  finishing requirements,
- $\bar{Z}$  family identifier,
- end preparation for welding,
- welding specification,
- pallet identification,
- pipe-piece identification,
- special work instructions (e.g., loose fitting a flange),
- flange thickness, and
- distance from flange face to branch centerline, etc.

Figure 1-9 illustrates how such data can be coded and applied to a specific pipe piece.

Many pipe-piece drawings must be developed for each new ship design. The design process follows clearly defined steps some of which require much computation. Others require repetitive reference to basic design data. Thus, computer-aided design tools improve timeliness, accuracy and productivity. Such programs typically provide:

- input-data error checking,
- modification of input data via standards,
- exact material quantities,
- fabrication information, and
- data used for estimating, planning, scheduling, executing and evaluating, e.g., type and length of weld per pipe piece, painting area per pipe piece, man-hours per pipe piece, man-hours per unit weight, weight per pipe piece, etc.



How designers create and classify pipe-piece designs critically influences both fabrication and assembly processes. When pipe pieces have to be bent, bends should be specified which can be formed after fabrication, e.g., bending after flanges are attached. Such designs are beneficial because, as shown in Figure 1-10, they can be treated as straight pipe pieces for most of their fabrication cycle. An appropriate target for designers is to designate 40% of the total number of pipe pieces as straight pipe or pipe that is to be bent after fabrication.

Typical goals for people who perform work-instruction design are:

- 5.5 meter pipe-piece lengths for on-unit and on-block outfitting (access for cranes is always provided),
- not more than 3.0 meter pipe-piece lengths for on-board outfitting or otherwise limited by what an assembly worker can safely handle,
- common supports for parallel pipe-runs and walkways,
- ganged bulkhead and deck penetrations, and
- standard dimensions such as for bulkhead and deck penetrations, branch positions and lengths, etc.

#### 1.2.4 Material Definition During Work-instruction Design

Planning functions performed by detail designers during their preparation of work instructions are crucial for effective PPFM. Such planning is the basis for all pipe-shop material and production controls. The planning essentials which detail designers provide are:

- Z designation of pallets, i.e., work packages for outfit assembly work organized by zone/problem area/stage, and
- Z classification of pipe pieces within each pallet, i.e., assigning each to a pipe-piece family, see Figure 1-11.

This matrix permits:

- detail design by zone,
- fabrication by pipe-piece family (problem area and stage), and
- grouping of pipe pieces from various families by zone for outfitting (palletizing), see Figure 1-12.

	MARKING & CUTTING	FITTING & WELDING	BENDING	ASSEMBLING
TRADITIONAL BENT BEFORE FABRICATION				
COMPETITIVE BENT AFTER FABRICATION				

Figure 1-10: Regardless of whether manual or automated processes are used, pipe pieces which remain straight as long as possible, facilitate fabrication work and are easily rolled from one work station to the next.





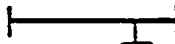



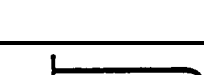
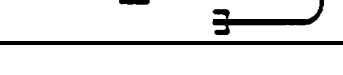

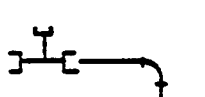
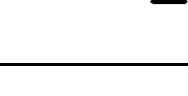
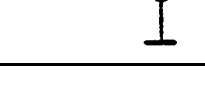
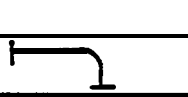
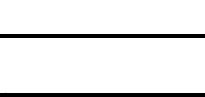


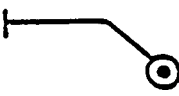


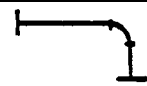



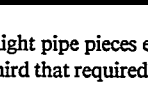
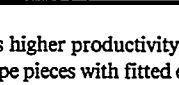
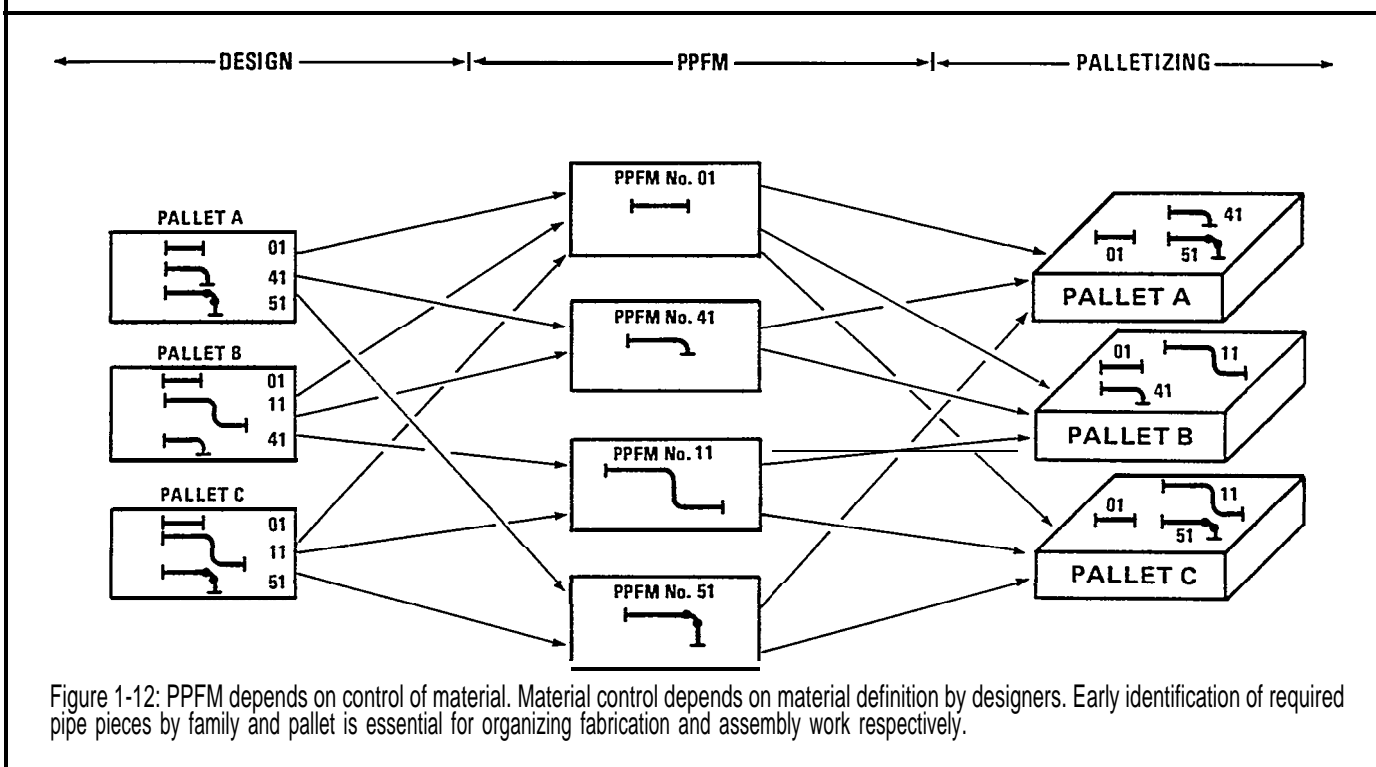
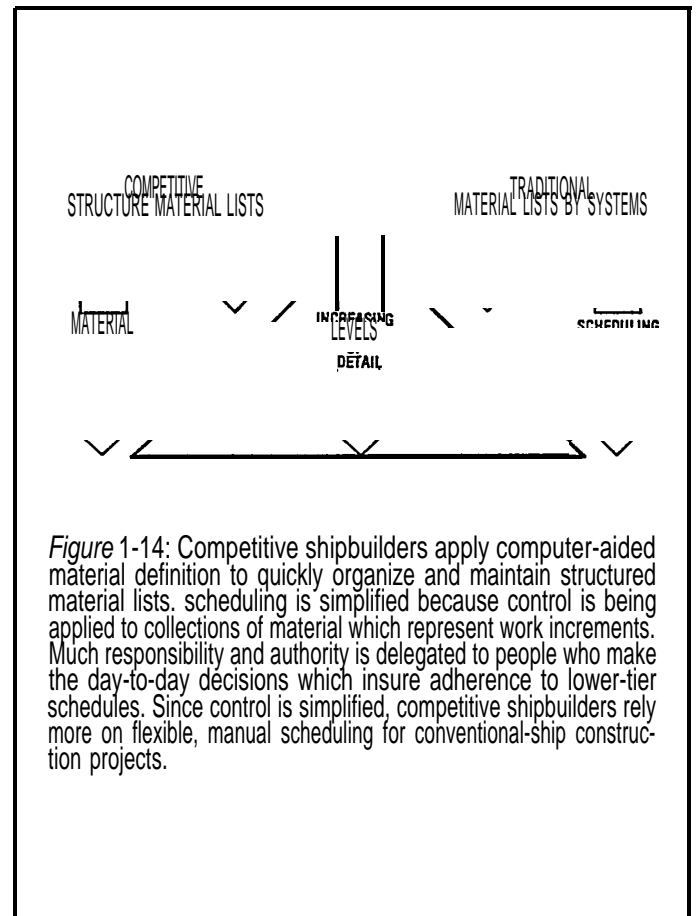
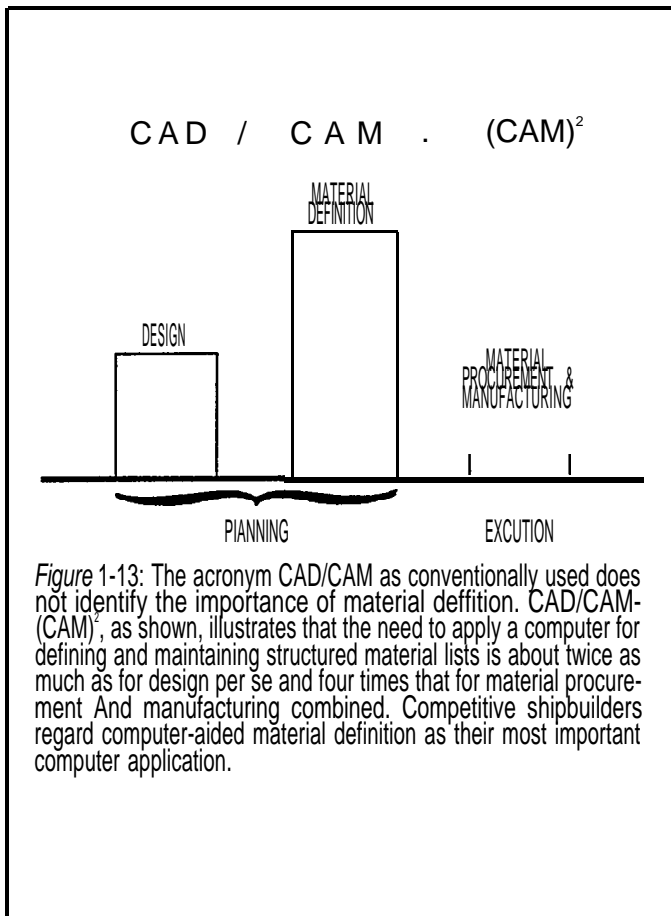
PPFM NO.	PIPE PIECE FAMILY		SKETCH	
01	Straight	$\leq 50\text{mm}$		
04	Straight	65~200mm		
07	Straight	$\geq 250\text{mm}$		
11	Bent After Fabrication	$\leq 50\text{mm}$		
14	Bent After Fabrication	65~200mm		
21	Radiographic tested			
24	Hydrostatic tested	$\geq 40 \text{ kg/cm}^2$		
27	Hydrostatic tested	$< 40 \text{ kg/cm}^2$		
31	Plastic			
34	Bent by heating			
41	Bent Before Fabrication	$\leq 50\text{mm}$		
44	Bent Before Fabrication	65~200mm		
51	Assembled	$\leq 50\text{mm}$		
54	Assembled	65~200mm		
57	Assembled	$\geq 250\text{mm}$		

Figure 1-11: Typical Pipe Piece Families. Maximizing the relative number of straight pipe pieces ensures higher productivity. For necessary bends, the fitting man-hours for pipe pieces that are cold-bent after fabrication are one-third that required for pipe pieces with fitted ells. Pipe shop productivity depends on designers' knowledge of manufacturing methods and costs. More pipe-piece family classifications are included in Appendix A.





Information developed by designers, having more than one character, allows rapid, detailed and accurate forecasts of the impact of outfit-assembly requirements on pipe-shop capacity. No less important, the same information is the basis for their preparation of structured bills of material. These link the various material lists for pipe pieces (MLP) for a specific outfit-assembly work package to the material list of fittings (MLF) needed to support the package. As GT necessarily features relatively small work packages in order to regulate work flows, as shown in Figures 1-13 and 1-14, production control through control of material is of utmost importance.<sup>5</sup>

Figure 1-15 illustrates the relationships between diagrammatic, composites, pipe-piece drawings and their respective material lists. Figure 1-16 depicts the data flow for a pipe-piece calculation program. This figure also shows how standards' files eliminate repetitive definition of material specifications and other such chores. Each need is defined once and placed in a standards' file by system.

Family identifiers also permit managers concerned with productivity to very exactly monitor a designer's contribution to pipe-shop productivity. Other indicators which are particularly useful for assessing designers' contributions to pipe-shop productivity are

- I number of pipe pieces that are to be custom manufactured from sketches or mock-ups made on board, and
- I average length per piece.

For increased productivity, the former should be minimized and the latter should be maximized. Typically for approximately 3,500 engine-room pipe pieces in a 20,000 DWT ship, less than 11% and more than 1.85 meters respectively.

The numbers of pipe pieces per family, which have been designated for a 60,000 DWT tanker by a competitive shipyard, are tabulated in Appendix A. A decision logic table and formats for family coding used to guide designers, are also included in Appendix A.

<sup>5</sup> A senior manager in the world's foremost shipbuilding industry said "In Japan we have to control material because we cannot control people." Y. Mikami to L.D. Chirillo, June 1980.

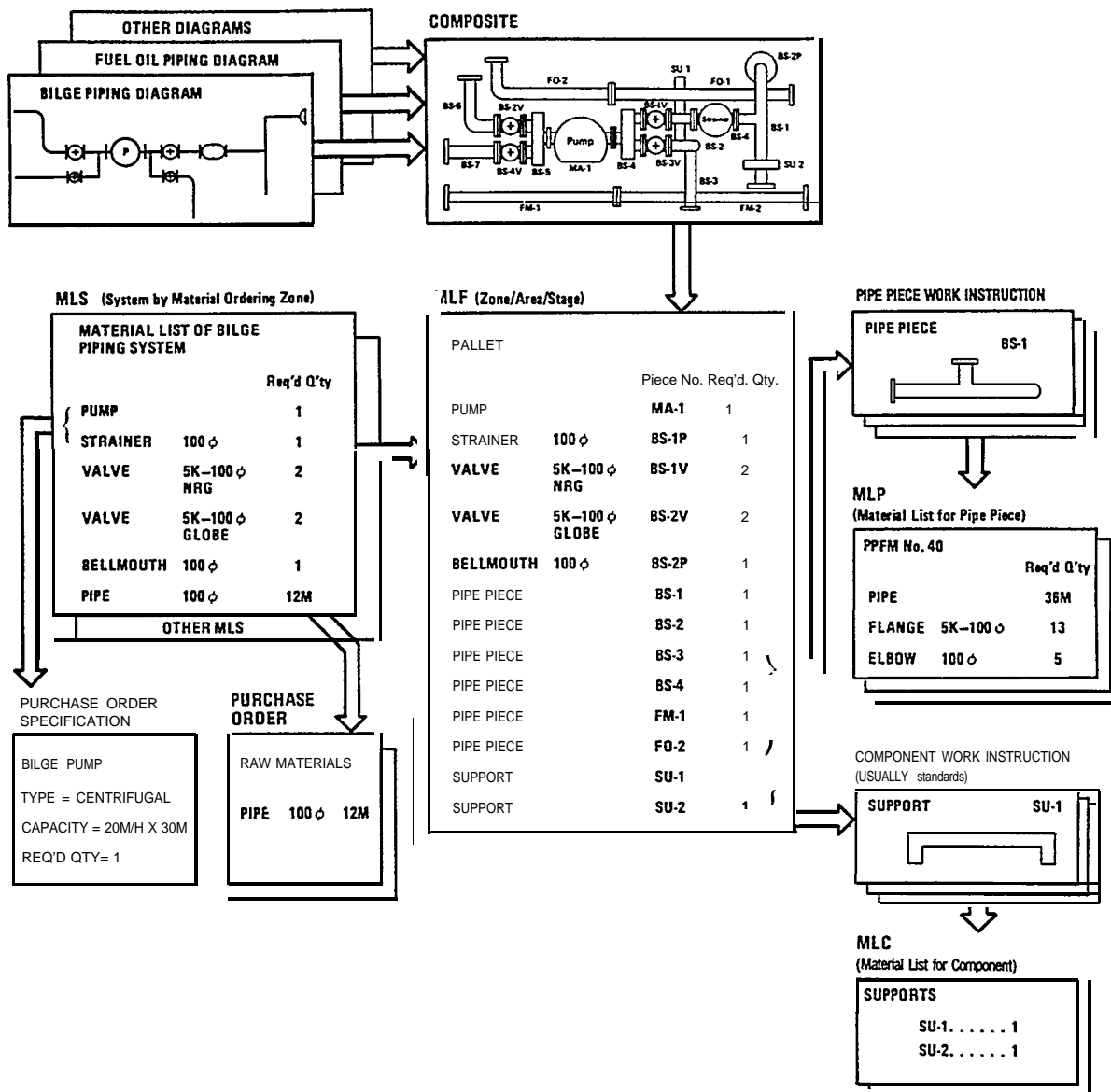
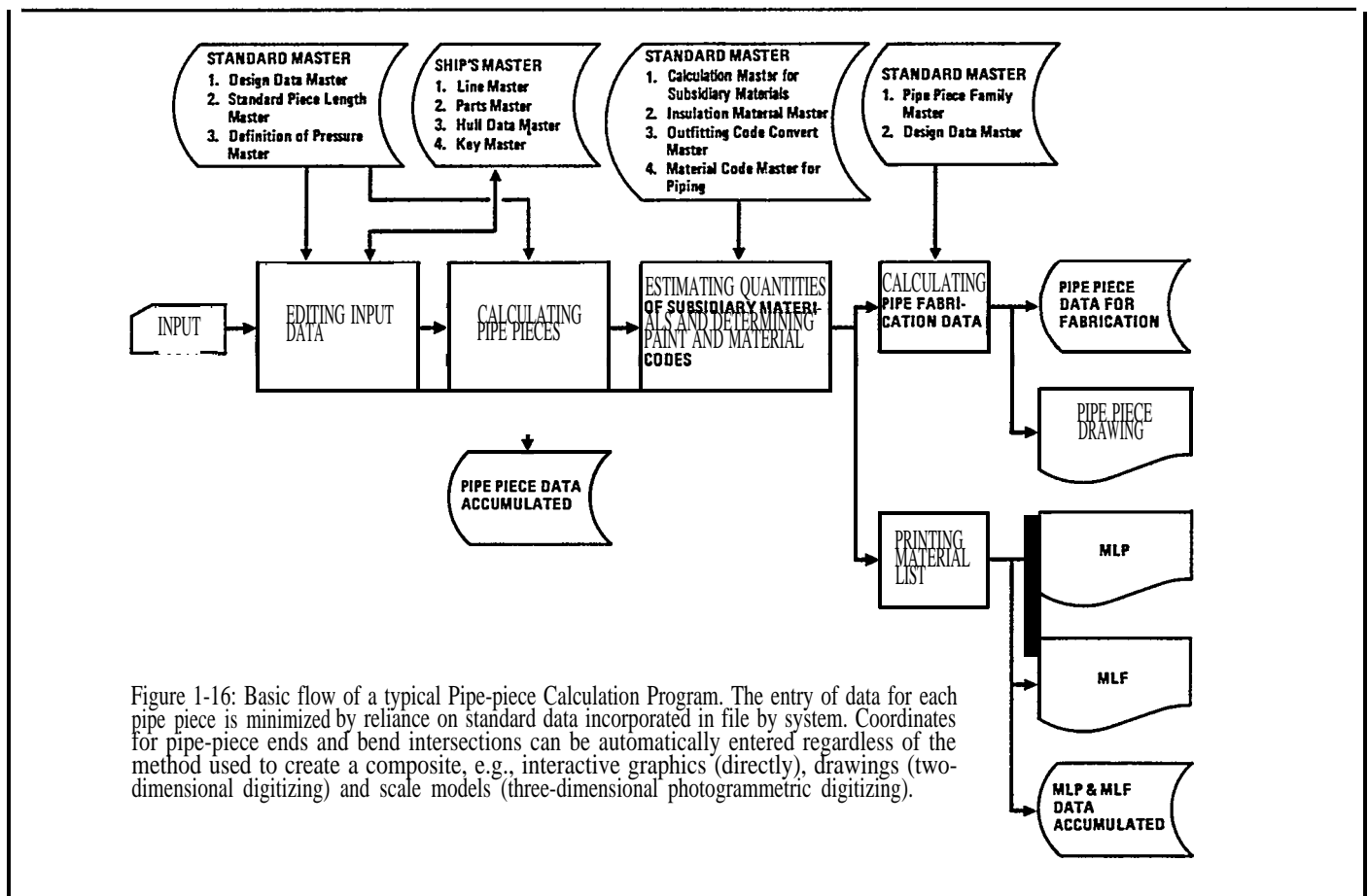


Figure-15: Relationships between diagrammatic, composites, fabrication-work instruction and their respective material lists.



### 1.2.5 Material Control

In order to simplify estimating, procurement and inventory, materials required for manufacturing pipe pieces are classified by unit price, frequency and quantity of use and certain other determinants. Consistent with integrated control of manpower budget, schedule and material, production control specialists devise material classifications and pertinent guidance for their use. Another planning function performed by detail de-signers is to assign the classifications accordingly. The materials for pipe pieces, just as the materials for other interim products, as shown in Figure 1-17, are classified as:

- 1 Allocated (A)
- 1 Stock (S), and
- 1 Allocated Stock (AS).

A are of special nature, e.g., relatively expensive copper-alloy pipe needed in small quantities. Procurement is made for a particular ship, e.g., A materials are not stocked.

S are common to most ships, e.g., small, slip-on flanges and inexpensive welding rod. These materials are procured in economic batches at intervals determined by their rates of consumption (high-low inventory).

AS are any A or S materials which historically have caused problems that justify special controls.<sup>6</sup> The problems can be of any nature, but usually they relate to shortages and surpluses. AS materials vary for each shipyard. As an example, in certain shipyards they include steel pipe, preformed fittings (ells, tees, and reducers) and valve operators.

### 1.3 Capacity Planning and Scheduling

Figure 1-18 illustrates the hierarchical nature of schedules which address all fabrication and assembly work. As they integrate inherently different types of work, i.e., hull construction, outfitting and painting, the schedules necessarily are:

- c control mechanisms which command work increments for fixed times, and are
- Ž organized at each level to provide constraints for lower-level, more detailed schedules.

Emphatically, schedules are based upon:

- 1 manpower expenditure, production progress and productivity indices that reflect normal shipyard performance, and
- 1 normally available subcontractor resources.

<sup>6</sup>The controls are addressed in Chapter 4.0 of "Outfit Planning - November 1979" by C.S. Jonson and L.D. Chirillo for the National Shipbuilding Research Program.



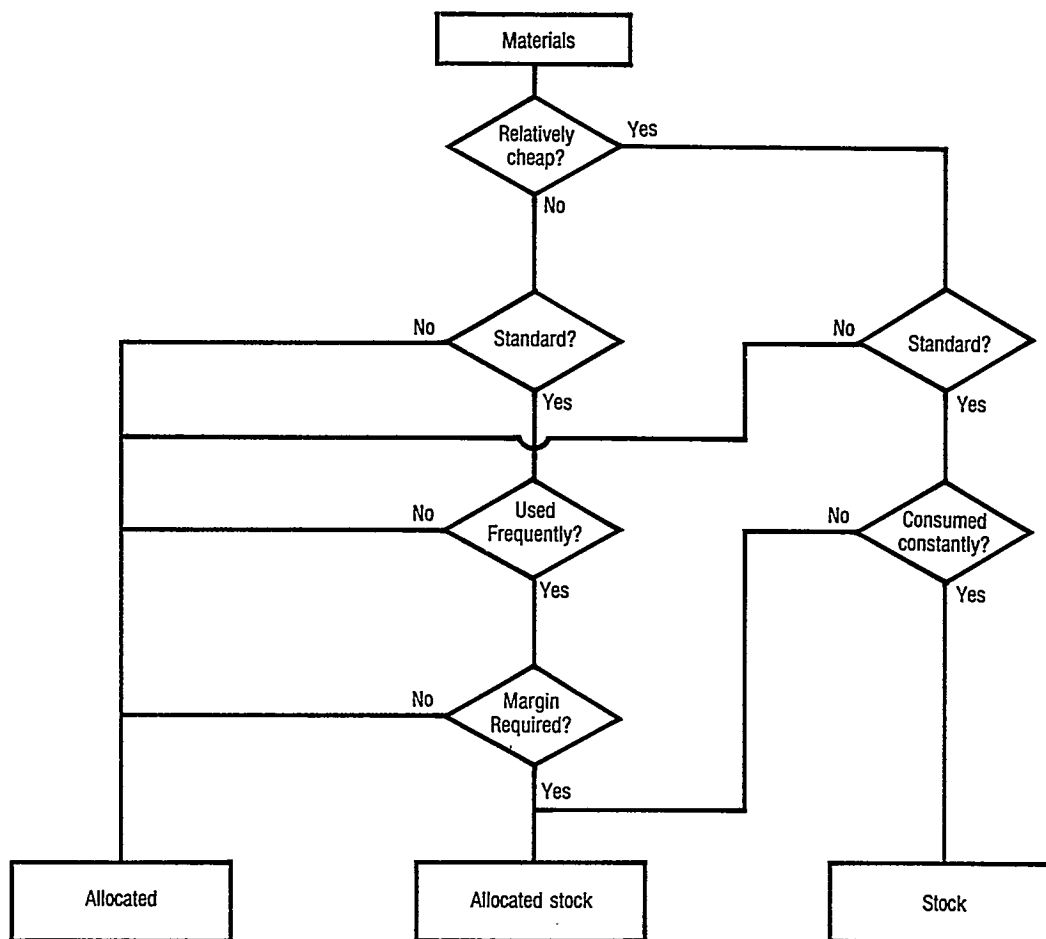
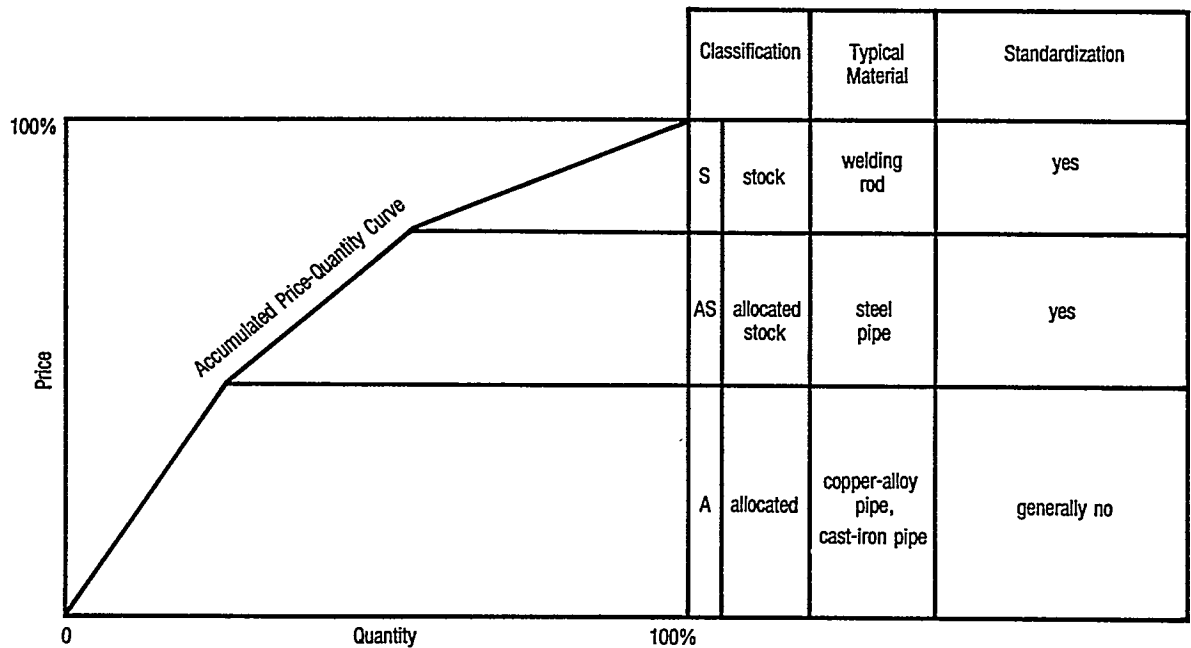


Figure 1-17: Material Control Classifications. A third classification, AS, in addition to the two traditionally employed, A and S, focuses on materials which historically cause problems of any nature.

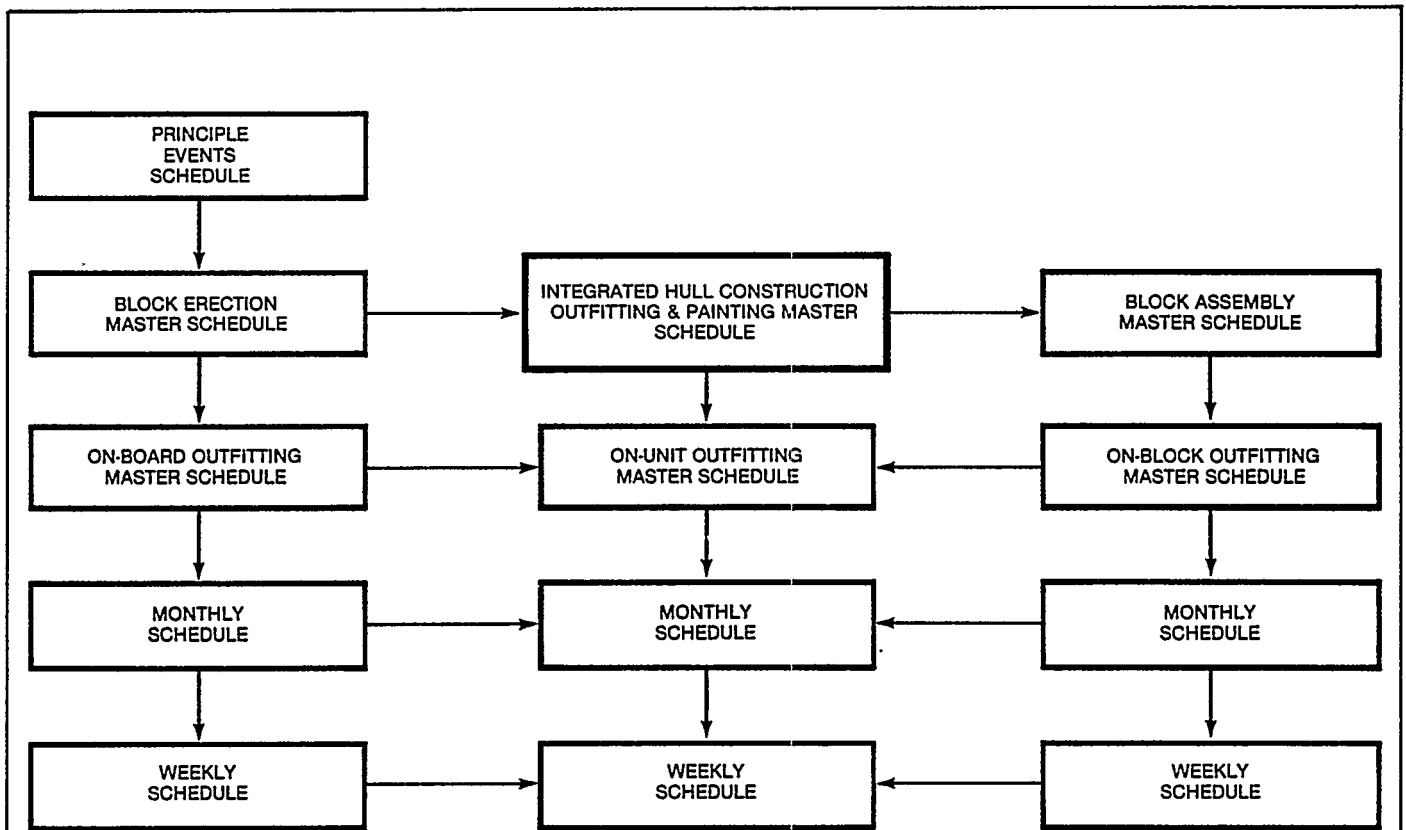


Figure 1-18: Organization of Integrated Hull Construction, Outfitting and Painting Schedules. A pipe-shop work load is fixed by the outfitting master schedules.

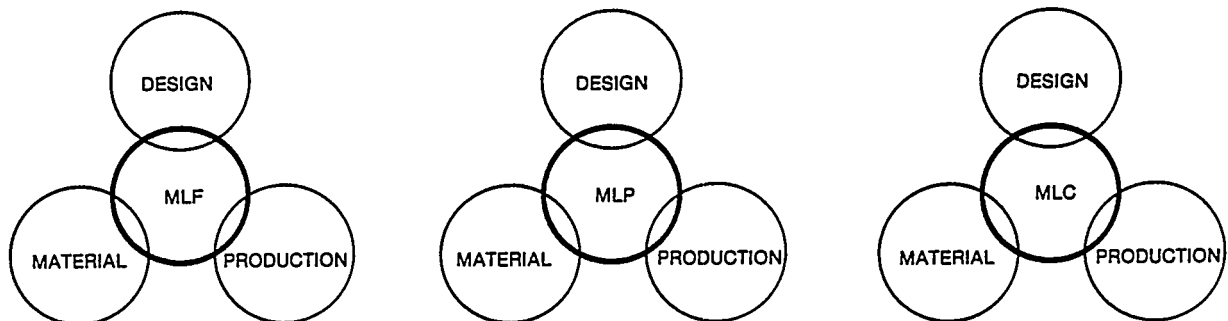


Figure 1-19: MLF, MLP and MLC are Information Links. They are collections of materials which represent work increments. They are widely used to follow-up on flows of drawings, material and work. They are also used to assess productivity.

### 1.3.1 In-house

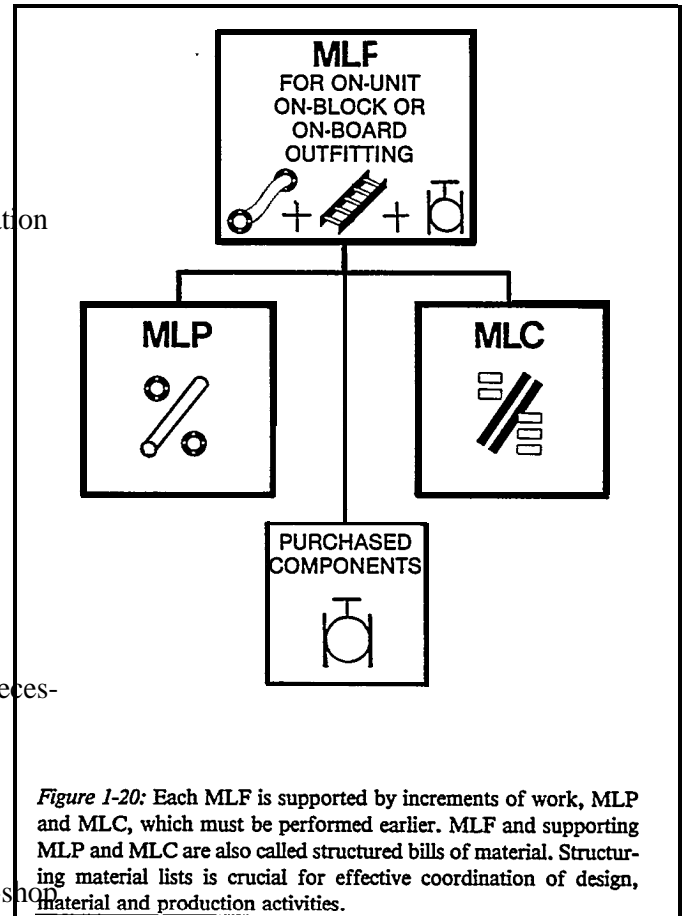
For convenience, MLF, which designates the material list of fittings for an outfit work package, is also used to designate a specific part of an arrangement and the required outfit-assembly work; see Figure 1-19. Similarly, MLP, which means the material list for a pipe piece, is used to designate the required work instruction and the associated fabrication work. MLC, which applies to a component other than a pipe piece, is used the same way. Each MLF is supported by increments of work which must be performed earlier, i.e., MLP and MLC; Figure 1-20.

Further classification of MLP by pipe-piece family is essential for planning pipe-shop operations in accordance with Group Technology (GT). Grouping MLP in order to create work lots simplifies control.

Typically, a work lot is the volume of work for loading a shop during one workweek. An ideal lot contains a quantity and mix of pipe pieces which achieves uniform work flow for each operation and optimizes tool set-ups, e.g., pipe-bender die changes. A reasonable number of such changes is necessary because limiting a lot to just one pipe diameter, i.e., keying all work flow to bender operation, creates more in-process storage with correspondingly higher overall costs. Further, this requires design and material procurement efforts that are not sequenced to match optimized outfit-assembly requirements. If this overriding requirement is ignored, such as by a manager concerned only with pipe-shop operations, i.e., apparent performance, there is adverse impact on real performance which must consider productivity for the entire shipbuilding process.

Obviously, detail-design output must also include a description of each pipe piece including type, linear measure, number of welds, paint system and surface area to be painted. Since the total number of pipe pieces that can be produced per week is also dependent on the complexity of pipe pieces, managers should also monitor man-hours per type and linear measure of weld, and, man-hours per coating and area measure of surface, etc.

Rescheduling work to optimize flow can be accomplished only within certain limits. The process produces schedules which are leveled and balanced so that weekly work volumes do not unnecessarily fluctuate or exceed shop capacity. The leveling and balancing process is possible because of standardization of lead times by production controllers and inclusion of family identifiers in fabrication-work instructions by detail designers. Generally, the numbers of pipe pieces that must be considered require computer processing.



Pipe pieces for overhaul, conversion and other work should be included in leveling and balancing routines whenever their respective normal lead times can be accommodated.

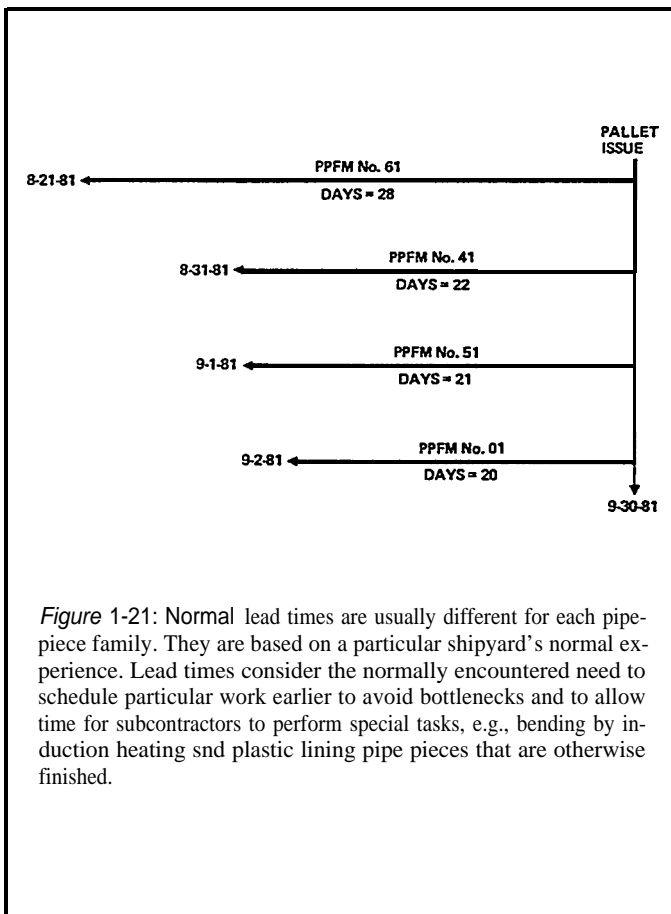
When the word "pallet" is substituted for MLF, pallets are outfit work packages classified by zone, problem area and stage. Sequenced, they comprise a *pallet list* which is scheduled before work-instruction (detail) design commences. In other words, a pallet list serves as a game plan for executing outfit-assembly work.

Each pallet for on-unit, on-block or on-board outfitting, because it contains pipe pieces from various families, is a mix of fabrication work and contributes to total pipe-shop work. Because all pipe pieces have been categorized into families and each family has a normal lead time, a list of pipe pieces that should be fabricated in a given week can be readily determined. In other words, the completion date for fabrication-work instructions for a particular pipe piece is its pallet issue date minus the normal lead time for its family; see Figure 1-21.

This methodology permits early capacity planning. First, man-hours required for each operation for each family is computed weekly. This results in a total man-hour requirement by work station within each production line, e.g., cutting, bending, welding, assembling and coating. The work load is leveled and balanced for each line by examining the workload on a particular work station and scheduling earlier any work exceeding normal capacity. For example, if the work load on a welding station presents a bottleneck, some pipe pieces which require welding are scheduled for the previous week. The lead times shown in Figure 1-21 anticipate such rescheduling based on a particular shipyard's experience.

### 1.3.2 Subcontracting

A schedule for outfitting on unit, on block and on board exists in the form of a pallet list which sequences the development of composite drawings. Pipe-piece family identifiers are assigned by detail designers as they develop a composite for a particular pallet. Thus, critical planning is performed even before time is taken to prepare fabrication-work instructions. Just this association of numbers of pipe pieces per family with pallets, permits *quick* assessment of capacity requirements and determinations of how many pipe pieces, by family, must be assigned to subcontractors. Reasonable time is available to negotiate pertinent subcontract terms.



Because of scheduling restraints, leveling and balancing routines minimize but do not eliminate work load fluctuations. Generally, a shipyard's pipe-shop capacity should be less than even the normally encountered, minimal work load. This avoids:

- unused shipyard capacity during low work loads, and
- maintains a constant working relationship with several subcontractors who are relied upon to absorb workload peaks.

Large fluctuations in subcontracted work might jeopardize the stability of a few regularly used subcontractors in terms of work load and income. This problem is significantly reduced by distributing the work among more subcontractors so as to minimize the effect of large fluctuations on any one of them.

Ability to foresee pipe-piece fabrication work loads by families, permits a shipyard to reserve portions of subcontractors' capacities in the same manner that mill reservations are made for steel plate.

Preassigned purchase orders which are complete except for the designation of specific pipe pieces during specific periods, permit remaining make-or-buy decisions to be delegated to the pipe-shop manager. These decisions are made at a weekly meeting at least three workdays before the pertinent work-week. The threeday period is for delivering work instructions and necessary materials to the subcontractors. Furnishing the required materials provides a practical means for control of material quality, timeliness and costs. A shipyard's ability to purchase materials in larger quantities results in lower unit costs.

Subcontracting is especially productive when special facilities are required such as for plastic-lining steel pipe or high-frequency induction heating for small-radius bends in large diameter pipe.

In order to develop subcontractors who literally serve as an extension of a shipyard, special management attention is required. A small staff, representing both the pipe shop and the quality control section should be regularly assigned and charged exclusively with providing technical support to pipe-piece fabricators. The assistance should include instructions in the shipyard's information formats, terminology, methods etc. With such aid even the smallest of firms, having no design or material procurement departments, can provide significant pipe-piece fabrication services.

## 2.0 SHOP OPERATIONS

### 2.1 Work Flow

Increasing productivity through production-line principles requires standardized work processes, i.e., procedures, facilities, skills, man-hour requirements and durations. In theory, each production line consists of only sequenced activities, e.g., marking, cutting, assembling, etc., needed to fabricate pipe pieces for one family. As this would require needless duplication of facilities, the pipe-piece flows for various families are selectively merged and coordinated. A singular goal is to avoid, or at least minimize, reversals in the direction of basic work flow.

Routings are established so as to maintain families while sometimes joining them based upon similarities of required work processes. Figure 2-1 illustrates commonalities in processes which are the bases for determining how families can share flow lanes.

Work flows may be virtual, i.e., existing facilities do not necessarily have to be rearranged. Regardless of whether flows are real or virtual, flow patterns will differ based upon the area allocated for pipe-piece fabrication, the number and sizes of doors in the pipe-shop building and the arrangement and capacities of available facilities. Other factors that influence flow patterns are:

- the degree, by pipe-piece family, that peak work loads are normally offset by subcontracting, and
- what work processes are normally subcontracted regardless of workload, e.g., plastic-lining steel pipe and small radius bending of large diameter pipe.

PIPE PIECE FAMILY		FABRICATION SEQUENCE					TREATMENT SEQUENCE					FLOW LANE	
CODE	NAME	CT	BN	FT	WL	GR	PK	PT	LN	GL	ETC.	CODE	NAME
01	STRAIGHT	1		2	3	4	5	6				AA	STRAIGHT PIPE
11	BENT AFTER FAB	1	5	2	3	4	6	7					
64	LINED	1		2	3	4	5		6				
68	GALVANIZED	1		2	3	4				5			
41	BENT BEFORE FAB	1	2	3	4	5	6	7				BB	ASSEMBLED PIPE
51	FABRICATED PIECE	1		2	3	4	5	6					
65	LINED	1	2	3	4	5	6		7				
69	GALVANIZED	1	2	3	4	5				6			

**LEGEND**

CT: Cutting	BN: Bending	FT: Fitting, assembling, etc.	WL: Welding
GR: Grinding			
PK: Pickling	PT: Painting	LN: Lining	GL: Galvanizing

Figure 2-1: Pipe-piece families are joined based upon similarities in required operations in order to optimize equipment utilization. This results in organization of flow lanes for shop control. The numbers under each process indicate the sequence of fabrication.

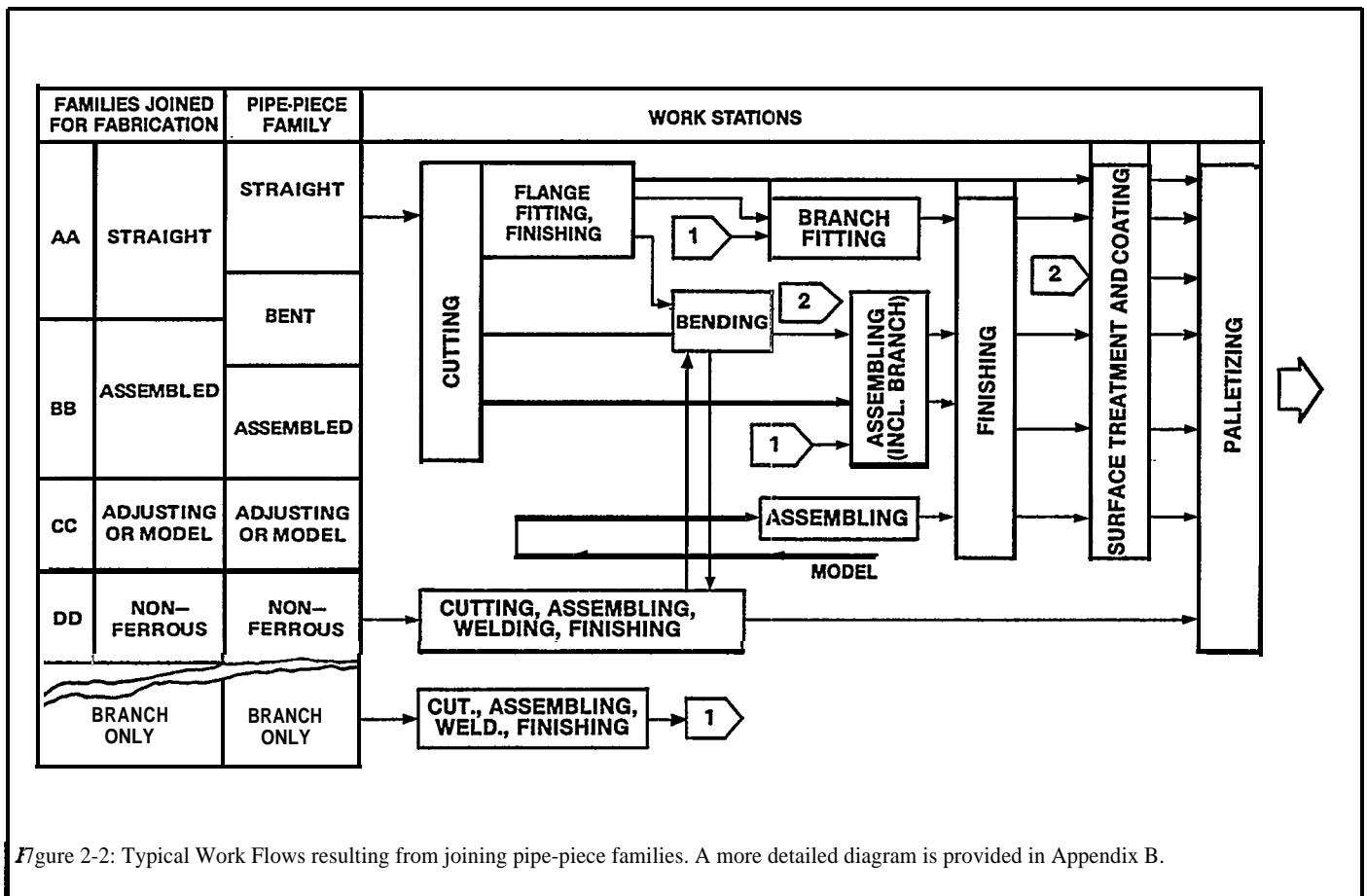


Figure 2-2: Typical Work Flows resulting from joining pipe-piece families. A more detailed diagram is provided in Appendix B.

Figure 2-2 schematically illustrates coordinated work flows for a manually operated, competitive pipe shop which employs PPFM. Figure 2-3 shows the shop arrangement and work flows in more detail. Photographs of the same shop's painting and palletizing areas are shown in Figure 2-4.

## 2.2 Shop Organization

The routing of PPFM work flows are peculiar to each shipyard's circumstance. However, basic managerial functions as described in Figure 2-5 are the same.

Further, PPFM is an industrial science. Implementation requires managers who understand the principles of Group Technology (GT) and a product-oriented work breakdown for building an entire ship, i.e., integrated hull construction, outfitting and painting. For example, they are required to manage statistical process analyses to improve pipe-shop methods which contribute to improving overall shipyard productivity. Thus, the pipe-shop positions of manager, deputy manager and planning and control manager are valuable training assets for further development of *shipbuilding engineers*.

There are no options. The realities of competition require that shipbuilding engineers/managers be

- college or equivalently educated,
- rotated in pipe-shop positions, and
- experienced in other shipbuilding functions.

The assignment of responsibilities to first and second level supervisors, i.e., foremen and assistant foremen, depends on both routing of work flows and palletizing requirements. Figure 2-6 shows how such responsibilities are apportioned for the pipe shop described in Figure 2-3. Figure 2-7 is a similar presentation for a smaller pipe shop which also employs PPFM.

PPFM employs production line-principles which include fixed work stations. However, workers are trained and continuously rotated in all jobs because:

- reassigning pipe-shop workers is the best way to adjust for different pipe pieces required in varying quantities,
- their awareness of how work stations impact on each other permit them to contribute to fine tuning flow lanes, and
- universal experiences are necessary to develop prospective foremen and assistant foremen.

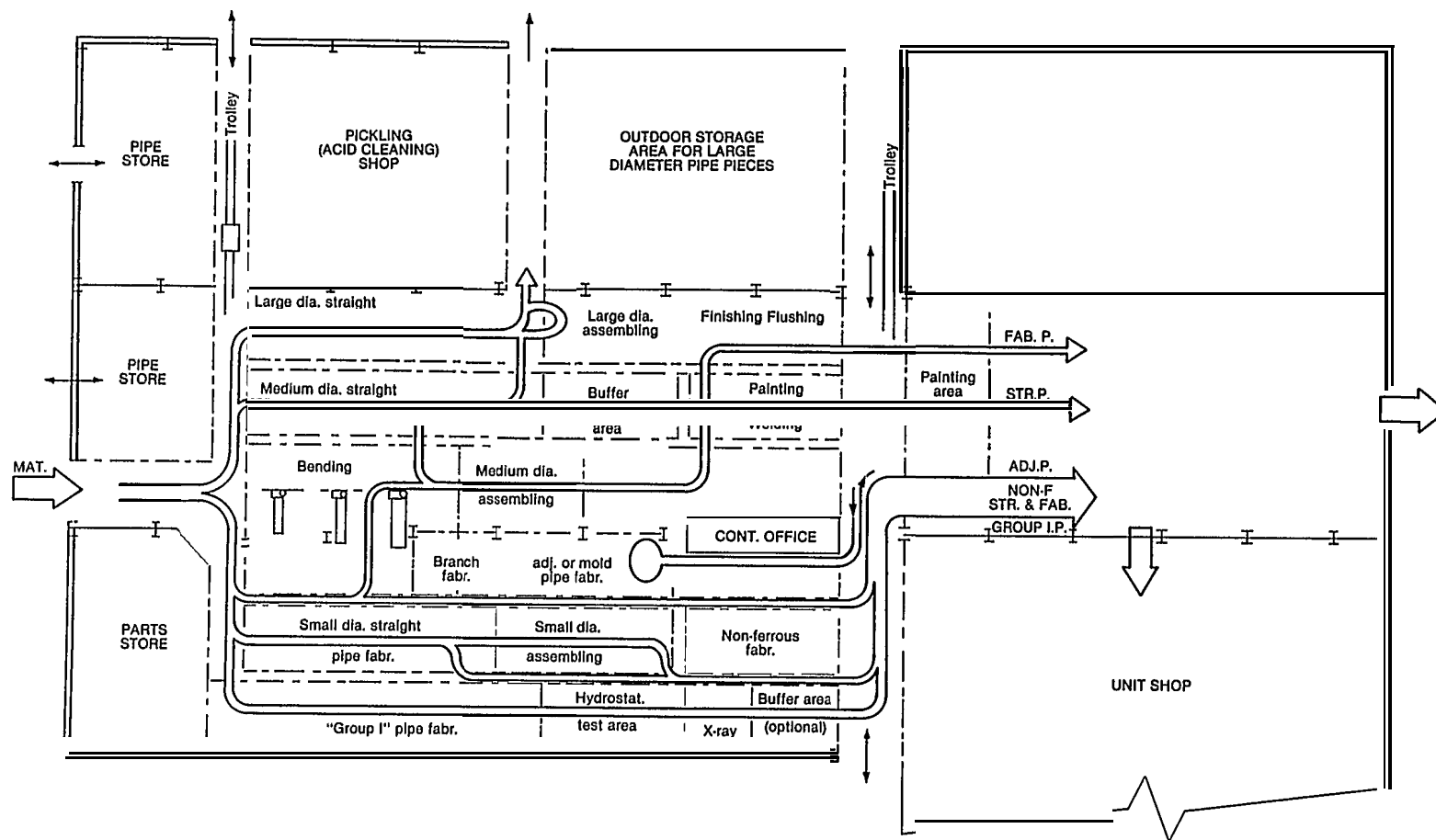
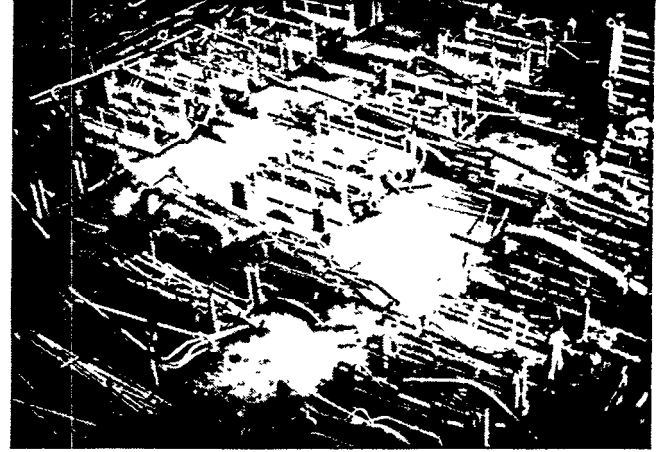
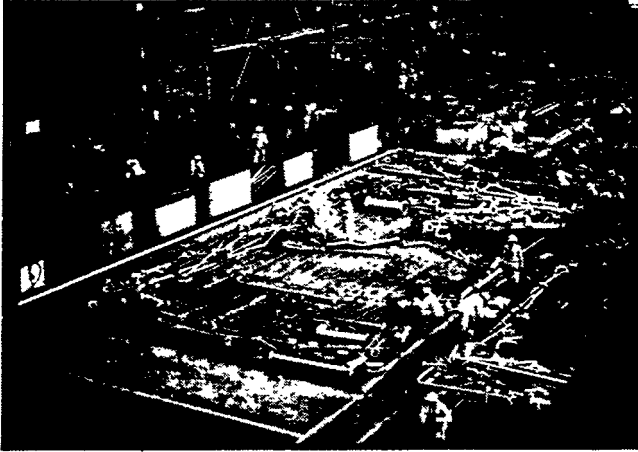
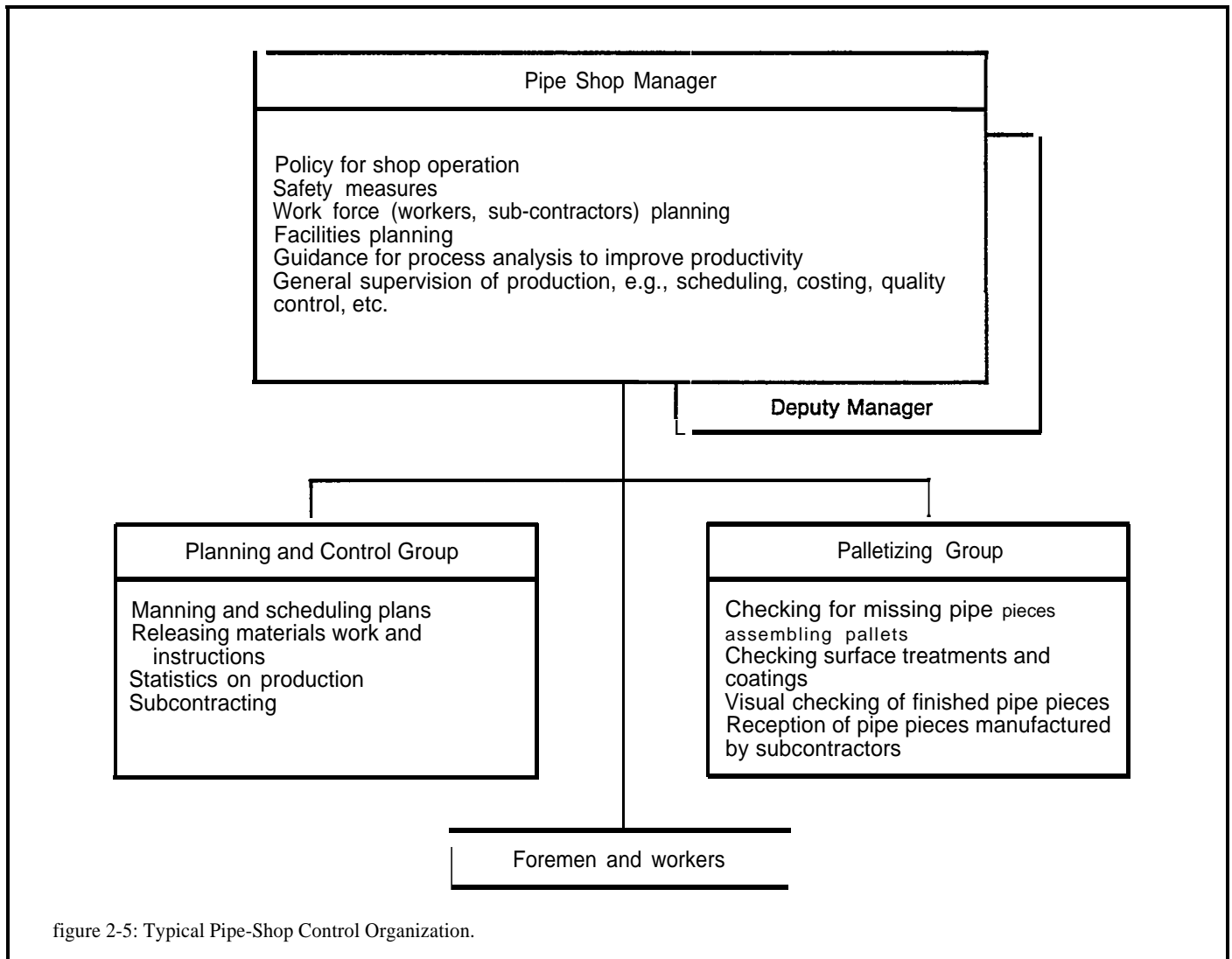


Figure 2-3: Typical work flows for the manually operated pipe shop in IHI Kure Shipyard which employs PPFM. Planned nominal capacity: 450 tons/month. Shop area less palletizing area: 4,167 square meters. Planned efficiency: 0.1 tons/month/square meter. Maximum output: 490 tons/month during construction of large ships. Current output: 260 tons/month for construction of medium sized ships. Productivity varies between 1 and 2 man-hours/pipe piece depending on ship sizes, required surface treatments, etc. Some painting is performed in the outdoor storage area for large diameter pipe pieces.



**Figure 2-4:** Pipe Shop, IHI Kure Shipyard. *Left:* Painting area. The control office appears in the left background. Welding stations are in between. *Right:* the palletizing area is next to the painting area and occupies 2,000 square meters.





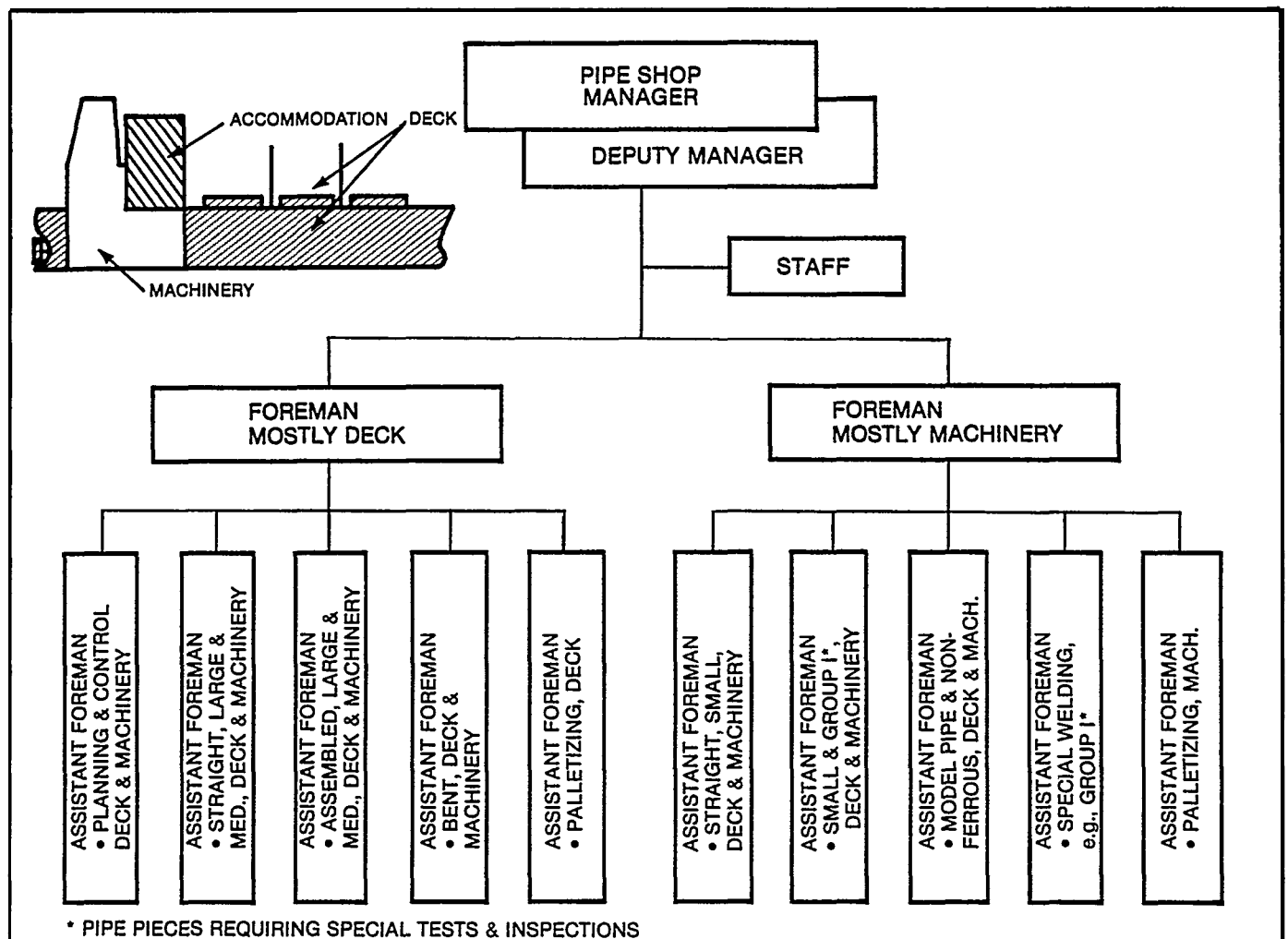


Figure 2-6: Organization of a shop which employs PPFM is dependent on how the various production lines are made to merge in order to establish flow lanes. Effective alternatives exist, but as PPFM is applied Group Technology all must reflect reasonable separation by problem areas. As shown, one way to apportion responsibilities is to separately address the basic outfit zones for which most pipe pieces are required (DECK and MACHINERY). This type organization is applied flexibly so that the shop manager can direct any requirements, e.g., pipe pieces for AC-COMODATION, anywhere in order to balance work flows.

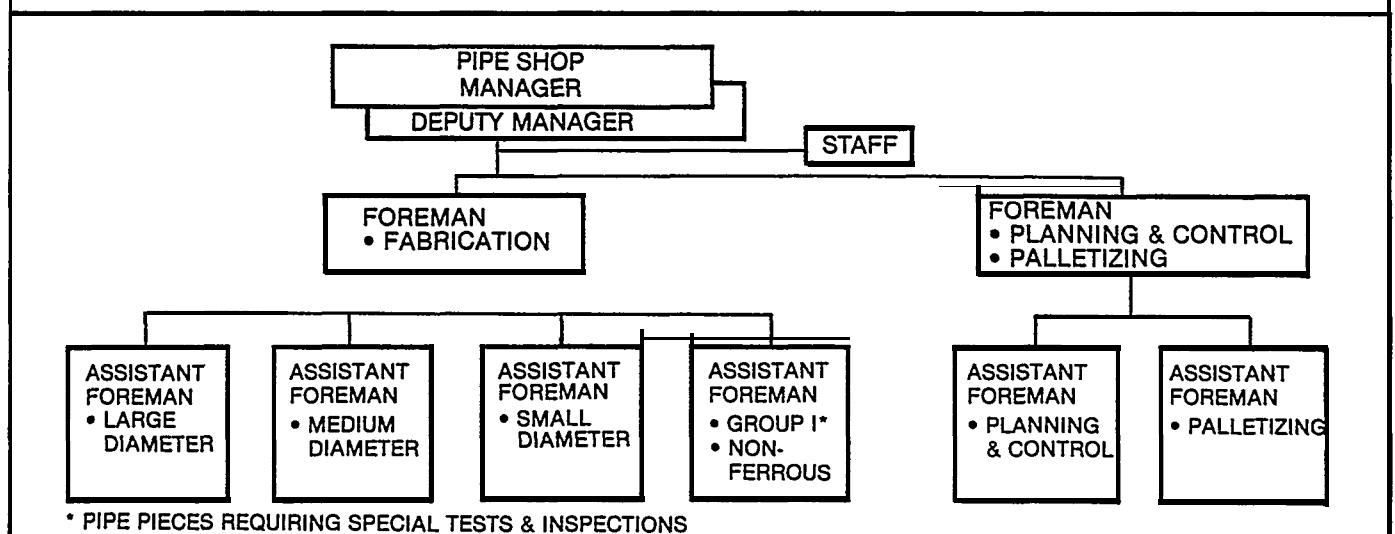


Figure 2-7: Another effective organization reflects separation into problem areas using diameter size as criterion. Similarly, this type organization is applied with a degree of flexibility.

## 2.3 Work Load Forecasting

Workload is governed by requirements imposed by outfit assembly schedules which virtually disregard pipe-shop capacity and backlog. The work thus imposed must be matched to available shop and subcontractor capacities in order to schedule efficient PPFM. Necessarily, there must be consideration of:

- . long-term measures, and
- . urgent problems which demand immediate solutions.

Changes in manpower and facilities which result from such considerations, should be consistent with the economic necessity to maintain in-house capacity at a relatively modest level and to regularly rely on subcontractors.

### 2.3.1 Long Term

Plans to adjust facilities, manning and subcontracting policies should be based on the total number of required pipe pieces or man-hours estimated for about the next six months. Circumstances sometimes require that the capacities of subcontractors be immediately reserved dependent upon their capacities relative to expected other demands.

### 2.3.2 Intermediate

Intermediate plans are based upon computer-aided analysis of pipe-piece requirements for the next two months. These are prepared separately for each pipe-piece family and work process as shown in Appendix C. Preparations are made for scheduling accordingly. If the workload greatly exceeds shop capacity, intermediate plans are revised in order to subcontract more work. Printouts are then obtained separately for in-house and subcontract work.

### 2.3.3 Weekly

The schedule resulting from intermediate planning is the basis for computer-produced weekly schedules, also shown in Appendix C, which are leveled and balanced to some degree. However, there is need to integrate "last minute" work as caused by loss, damage, owner changes and ship repair. These requirements are superimposed on each computer-produced weekly schedule. Family identifiers and normally expended man-hours per pipe piece per stage permit preparation of a summary of the combined effect on each flow lane; Figure 2-8.

FAB LANE	UNITS	LAST WEEK	REMAINING FROM LAST WEEK	THIS WEEK	NEXT WEEK
A-A	PCS	346	140	180	250
	MHRS	1570	643	352	1132
B-B	PCS	370	321	825	950
	MHRS	888	227	971	1045
TOTAL	PCS	716	461	1005	1200
	MHRS	2458	861	1323	2177
A-A WORKERS	DIR	20		20	20
	SUB	4		4	4
	XFER	5		2	2
B-B WORKERS	DIR	26		26	26
	SUB	4		4	4
	XFER	3		3	2
TOTAL WORKERS	DIR	46		46	46
	SUB	8		8	8
	XFER	8		5	5

SUB-CONTR.s	UNITS	MAX CAPACITY PER MONTH	COMPLETE LAST WEEK	SCHED THROUGH LAST WEEK	SCHED THIS WEEK	SCHED NEXT WEEK
A	PCS		485	444	658	
	MHRS	1700		905	862	
B	PCS		0	278	106	
	MHRS	700		133	105	
C	PCS		0	165	40	
	MHRS	100		106	36	
D	PCS		93	125	0	
	MHRS	900		655	0	
E	PCS		0	242	113	
	MHRS	230		223	123	
TOTAL	PCS					
	MHRS					

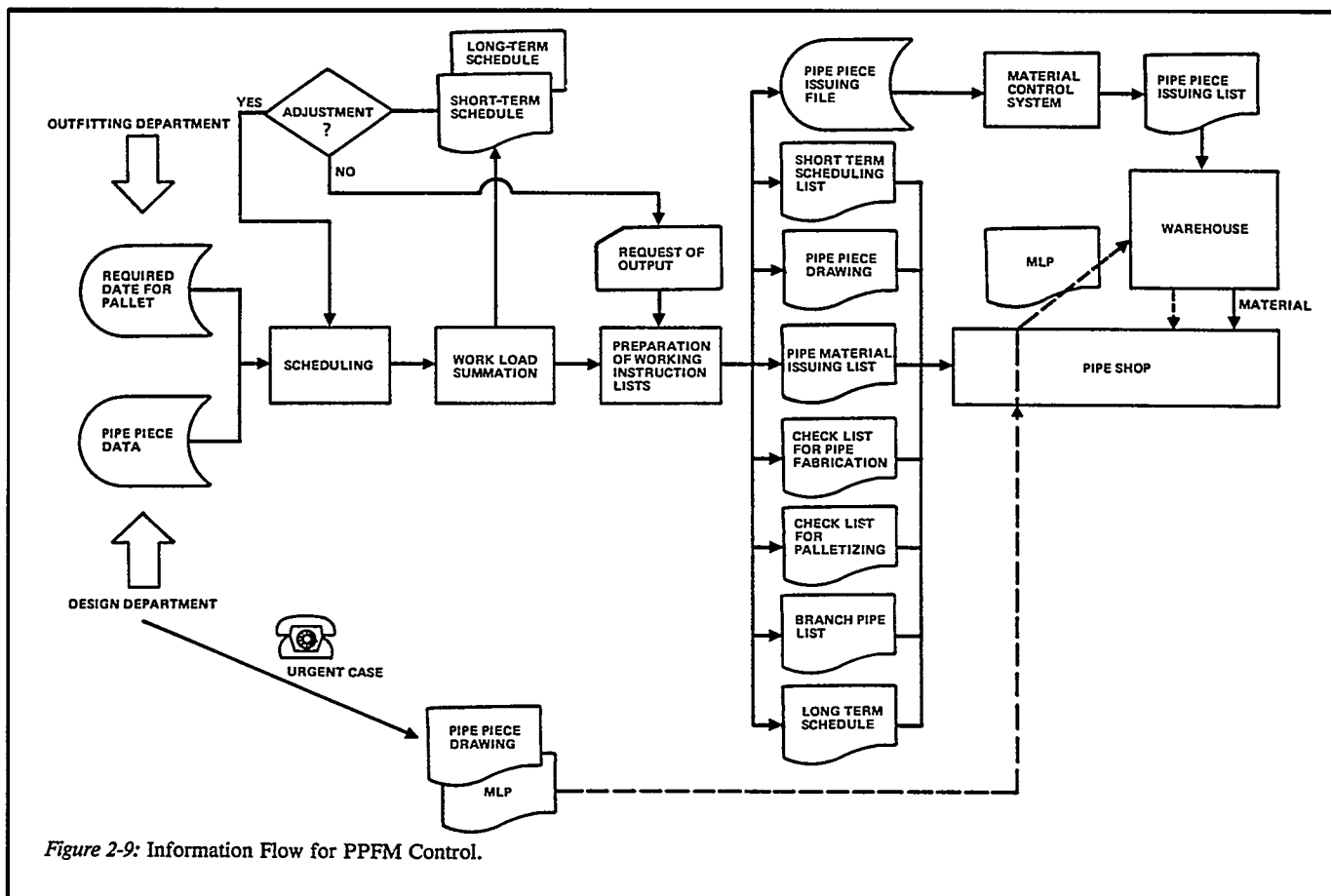
**Figure 2-8:** A fictitious summary of actual and anticipated work as used by a pipe shop manager during each weekly meeting to assimilate "last minute" requirements, apportion next week's work and adjust resources accordingly. (DIR: direct labor permanently assigned to pipe shop, SUB: subcontract, XFER: temporarily transferred workers from outfit-assembly sections; all are numbers of people)

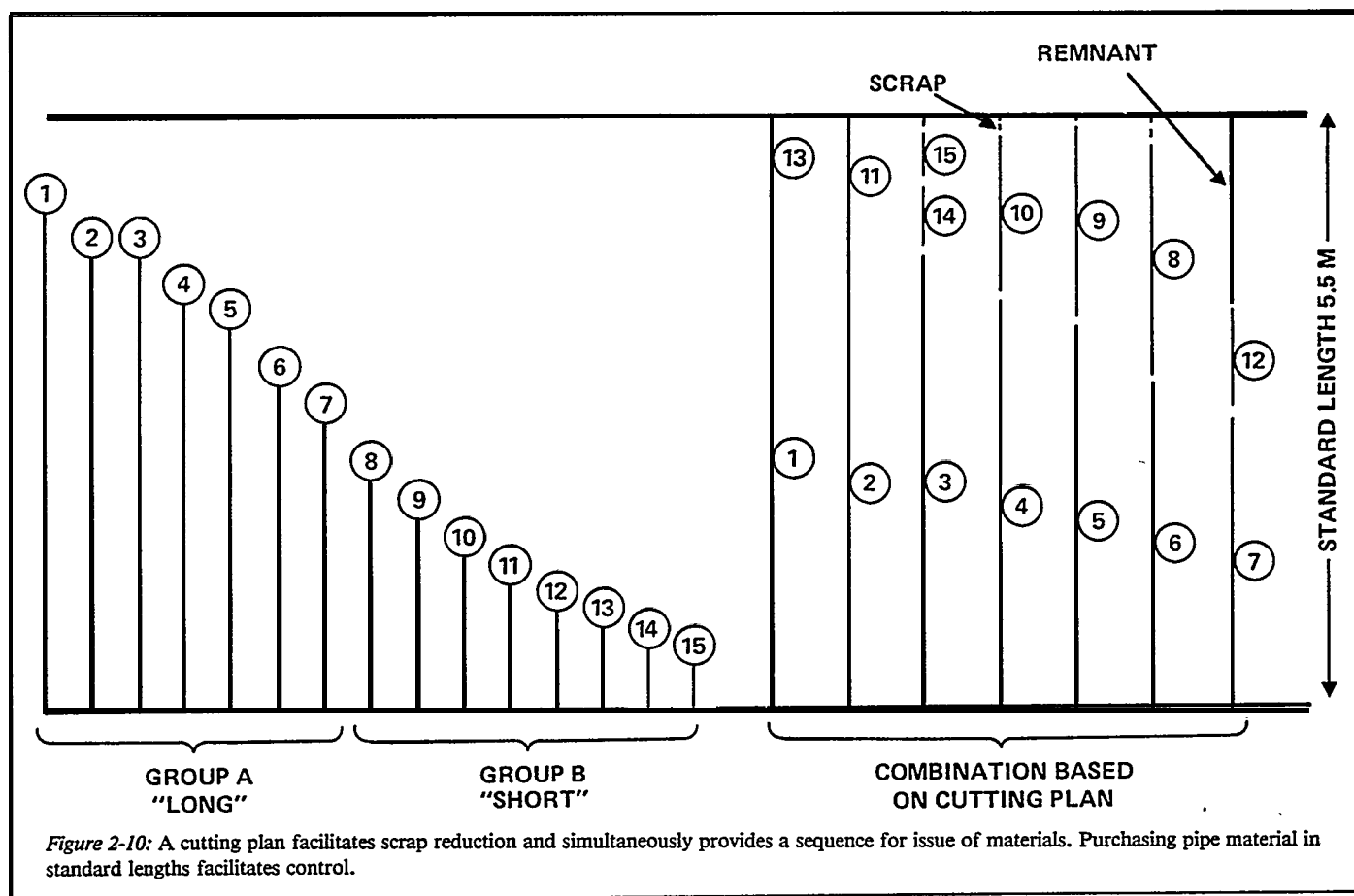
- . transfer of workers between flow lanes,
- . overtime, and
- assignment of more work to pre-approved subcontractors.

After the week's work is determined, further leveling and balancing is performed and reflected in detail schedules for each work station within a flow lane. Operators further refine such schedules within limits of their portions of a lot and by half day periods in order to optimize sequences at each work station.

Thus, planning and scheduling for PPFM proceeds in levels of increasing detail. At first, planners are concerned with identifying all required resources. Next, capacity planning is accomplished to minimize work fluctuations. A week before start of fabrication, plans for the next lot are completed and specific work is ordered. Finally, day-today operational adjustments are made.

Ideally, a shop manager's weekly meeting to define next week's work is held on a Tuesday. The previous day is for the shop planning and production control manager to make necessary preparations including analyzing progress information for the workweek just completed. Decisions made at a Tuesday meeting are a "go" sign for overnight computer-preparation of work and material orders. These are based on standard data concerning what, how and when work is to be performed. Distributions are made each Wednesday morning in accordance with the information flow shown in Figure 2-9. Thus, three workdays remain for necessary preparations including organizing and delivering materials to subcontractors.





#### 2.4.1 Cutting Plan

One of the printouts, a cutting plan, serves to obtain maximum utilization of pipe material; see Figure 2-10. Simultaneously, it is used to sequence work, required materials and work instructions. Sequencing pipe pieces to be cut, defines the order that flanges and other fittings, such as tees and reducers, are required. Thus, cutting plans control all work through control of material.

Cutting plan preparations address actual cut-lengths of pipe within a lot organized by nominal diameter, wall thickness and material type. These are subclassified as "long" and "short". Long and short requirements are matched in order to utilize as much as possible of standard length pipe material. As a rule of thumb, pipe pieces for the same ship are grouped together.

Standard limits for scrap are related to pipe diameters and to standard minimum branch lengths, e.g.:

- 300 mm diameter and larger-lengths less than 1,000 mm
- 250 mm diameter and smaller-lengths less than 400 mm

Lengths which exceed such limits and are unallocated, are remnants. If a separate cutting facility is employed for fabricating branches, remnant pipe is allocated by a separate cutting plan.

Information on a cutting plan includes:

- cut length and position,
- indication of scrap or remnant,
- identification numbers (Ship, MLF, MLP, Lot, Serial),
- pipe diameter and specification,
- schedule cut date,
- end preparation required,
- bending machine grasping position, and
- subsequent operation (flow lane).

#### 2.4.2 Subcontracting Expense Calculation

During the weekly meeting, if it is decided to utilize outside firms, designation of a subcontractor and the pertinent amount yields a printout of relevant expenses. These are based on files of normal work, unit prices, transportation costs, etc. A format for subcontracting expense calculations is shown in Appendix D.

### 2.4.3 Operations Control Lists

Additional printouts useful for operations control are

- **Branch-pipe List** which groups branch-pipe pieces to be fabricated in order to facilitate scheduling of pertinent work stations.
- **Pallet-comparison List** which is MLF data arranged more conveniently for palletizing finished pipe pieces. Features are incorporated to facilitate checks of fabrication-work progress.
- **Group I Pipe-piece List** which identifies pipe-pieces of a special nature which require tests that are to be witnessed by owner and/or classification society representatives.

Examples of operation control lists including those for surface treatment and coating schemes are in Appendix D.

### 2.4.4 Material-issue Confirmation

Typically, after operations control lists are prepared, pertinent data is transferred to the material control system. In response to a pipe-shop material-issue order, printouts list material sorted by specified issue dates and destinations. An example is included in Appendix D. Materials which are not in-stock are identified on a separate "shortage list".

### 2.4.5 In-process Identification

The numbers which appear on a cutting plan for each pipe piece to be fabricated identify ship, MLF, MLP, lot and serial. Once a lot is established for a particular week, by definition, all pipe pieces manufactured during that week will not jeopardize their respective pallet issue dates.

Internal pipe-shop operations, except for palletizing, are concerned only with problem area and stage classifications. Until palletizing, there is no need to maintain identities by ship, MLF and MLP. Thus, the cutting list also serves as a matrix for transforming these relatively complex identifications into simple lot and serial numbers; see Figure 2-11.

During palletizing, the final work process, pallet composition lists are employed to substitute specific ship, MLF and MLP identifiers for lot and serial identifications which are no longer needed, see Figure 2-12.

## 2.5 Material Flow

### 2.5.1 Input

**Successful PPFM is logical classification and control of material.** A warehouse organization dedicated to pipe shop methods is mandatory.

Where PPFM is effectively applied by a shop planned for 450 tons per month nominal capacity, the dedicated organization consists of one supervisor and three warehousemen. Of the latter, one has responsibilities for pipe, another is concerned with flanges and the third has cognizance of pipe fittings such as ells, tees and reducers. As each warehouseman is responsible for both receipts and issues, together they have handled over 900 tons per month.



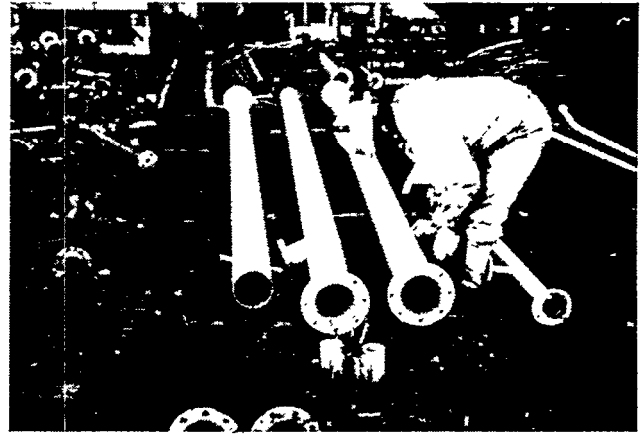
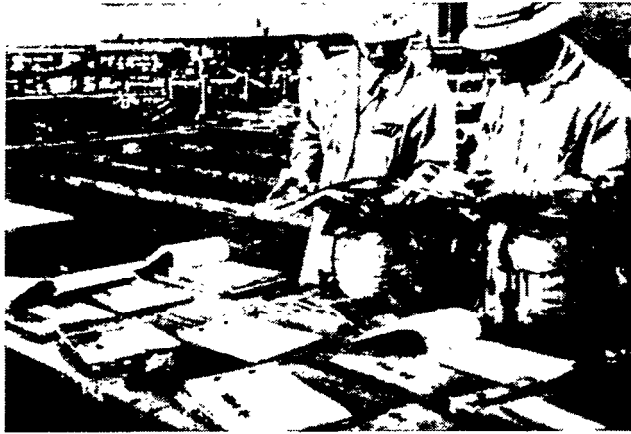
**Figure 2-11:** As shown, a single digit identifies a specific lot. The serial number peculiar to one pipe piece appears below. In some pipe shops a color code is used to identify pipe pieces in a specific lot (dab of paint or a colored tag on each pipe piece). A large calendar is color coded accordingly so that even a casual visitor can observe whether the work in process is on schedule.

Every Wednesday morning each warehouseman receives an appropriate printout which is a "picking" list for pipe, flanges or pipe fittings based on:

- final definition of the coming week's work at the shop manager's meeting the day before, and
- cutting plans which sequence work for specific work flows, e.g., for large, medium and small diameter and other flows and for subcontractors, see Figure 2-13.

### 2.5.2 Output

In order to fully exploit the principles of Group Technology (GT) for an entire shipbuilding process, pipe pieces are not regarded as complete until they have been painted and palletized. Coating and palletizing, as shown in Figure 1-1, are manufacturing stages just as much as welding and bending.



**Figure 2-12:** A single lot usually contains pipe pieces for different pallets needed for more than one ship. Also, because of different standard lead times some pipe pieces for a single pallet are produced in different lots. *Left:* Numerous printouts are needed to convert in-process identifications to ship, pallet and piece numbers as needed for palletizing. These same printouts served for checkoff purposes. *Right:* Identification numbers needed for palletizing are applied after coating each pipe piece.

The paint system applied to each pipe piece is consistent with that of its surroundings during outfitting on-unit, on-block and on-board. For example, when outfit assembly, clean-up, and touch-up work are completed, no pipe piece requires “catch-up” painting before finish undercoat is applied to the entire assembly.

Palletizing is simply collecting together pipe pieces needed for specific assembly work packages. The matrix used to shift from identification needed during fabrication to a specific assembly work package is described in Part 2.4.5.

The shop area and numbers of containers allocated for palletizing should anticipate that pipe pieces required for a particular pallet will sometimes be fabricated in different weeks preceding the pallet issue date. The number of weeks is dependent on the normal lead times established for pipe-piece families as described in Part 1.3.1. Thus, the collection of pipe pieces for a particular pallet could start two or three weeks before the last required pipe piece is produced.

In the interest of overall shipbuilding productivity, pipe-shop output is groups of coated pipe pieces, regardless of size and systems, which are required to support outfit assembly work packages organized by zone/problem area/stage.

## 2.6 Productivity Indices

A basic objective of PPFM is to collect costs by pipe-piece families. As shown in Figure 1-2, PPFM is based primarily on problem area and stage classifications. Thus, the only practical methods for collecting man power costs are by problem area, stage or a combination of both.

In the few cases where a production line is dedicated to one pipe piece family, collecting manpower costs by family is sufficient. Man power assigned and total weight and number of pipe pieces produced per unit time, yield averages for:

- man-hours/manufactured weight/family, and
- man-hours/manufactured piece/family.

However, production lines are intentionally merged for most PPFM in order to:

- avoid redundant facilities, and
- treat pipe pieces for some families as straight pipe early in their fabrication cycles.

Merged work flows impose a slight complication which requires collection of man power costs by work station (stage). Man power assigned, number of pipe pieces and weight per unit time yield:

- man-hours **anufact** weight/stage, and
- man-hours/manufactured piece/stage.

These two productivity indices are averages for an identical work process applied to a mix of pipe-piece families.

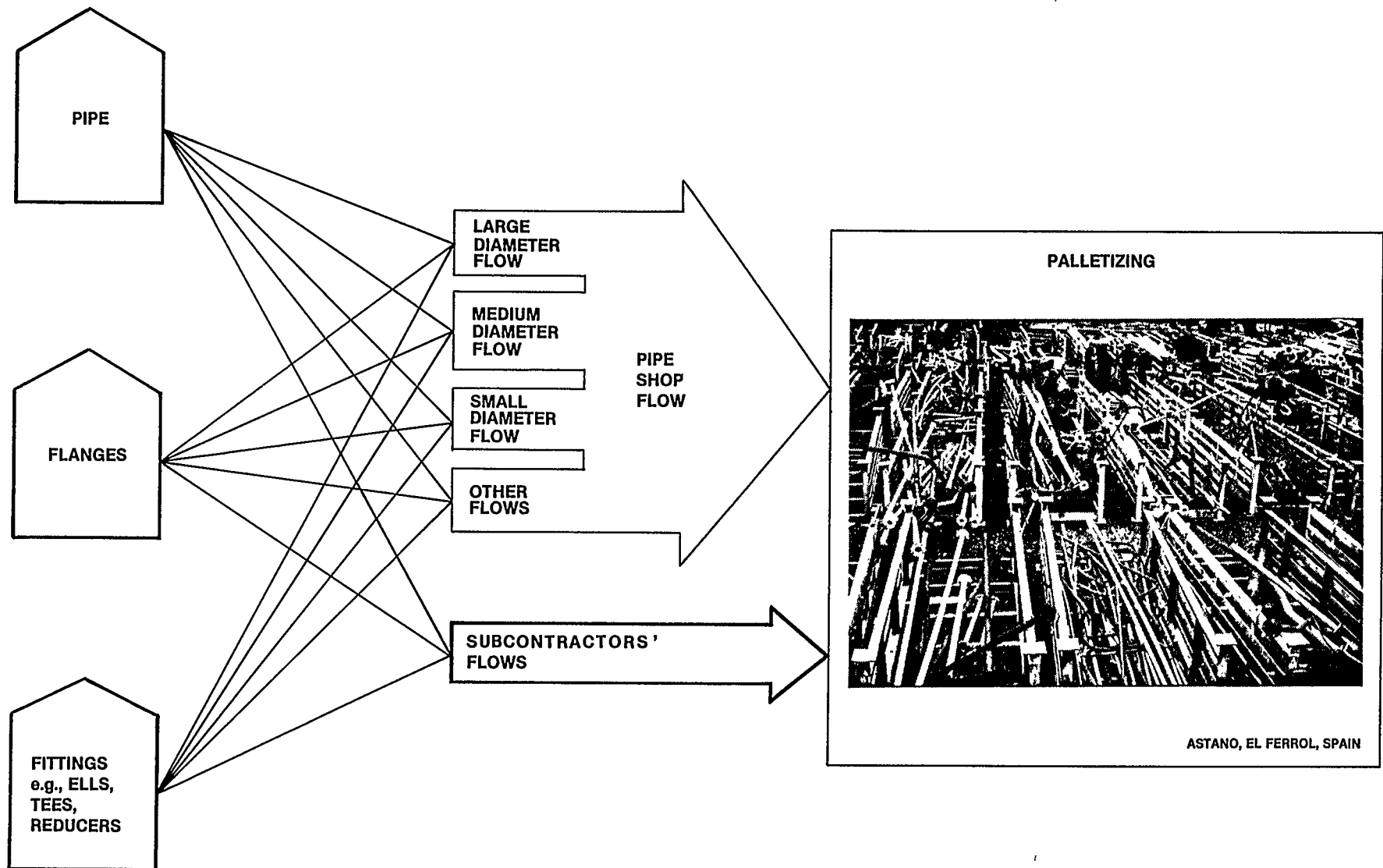


Figure 2-13: PPFM productivity is very dependent on accurate inventory records and timely deliveries of defined materials to specified addresses in specified sequences. Work flows for large, medium and small diameters and other flows are interdependent as shown in Appendix B.

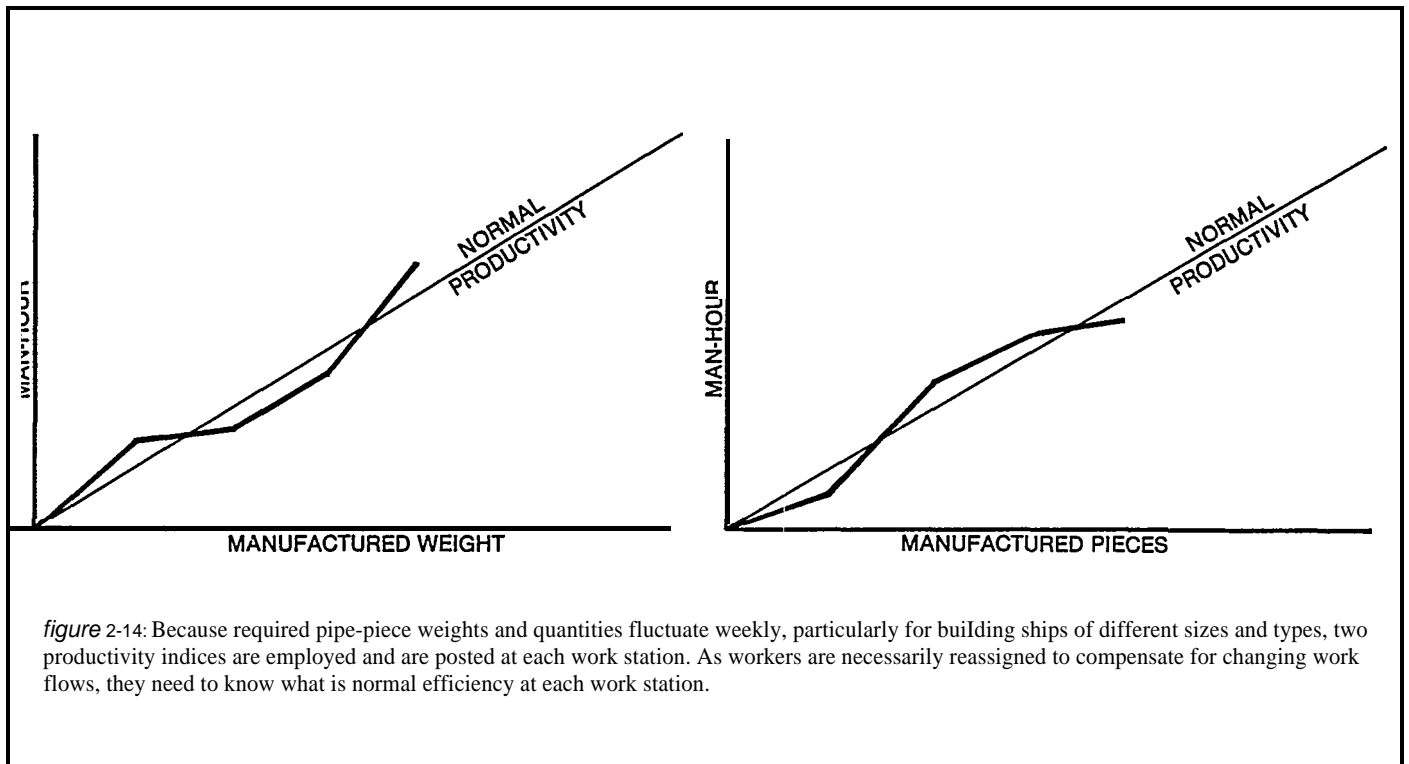
Because varieties and quantities of pipe pieces in lots differ from week to week, work flows change from week to week. A shop manager's most effective reaction is to transfer workers between flow lanes and adjust their numbers on work stations using man-hours/manufactured weight/stage and man-hours/manufactured piece/stage as guidance. These productivity indices are posted at each work station; see Figure 2-14. They convey to workers just assigned to a work station the history of *normal* efficiency at the station.

As pipe-piece families usually share common work stations, costs per pipe family are achieved indirectly. As shown in Figure 2-15, productivity indicators for only pertinent stages are summed. The summations are:

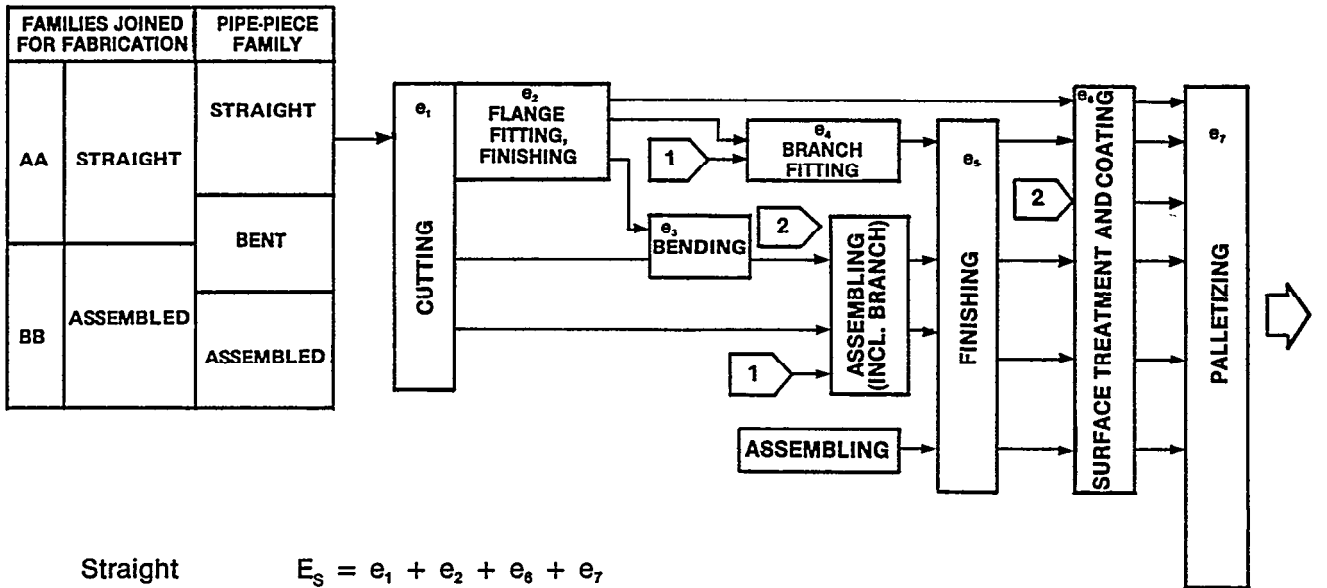
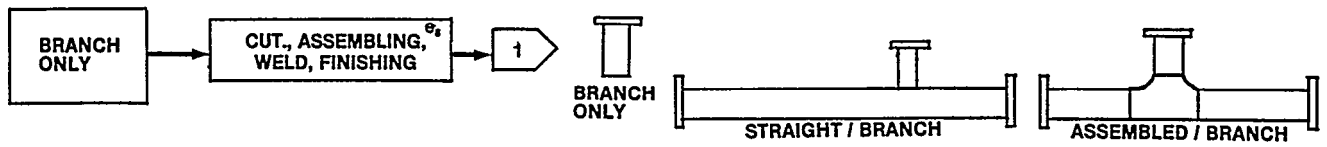
- o man-hours/manufactured weight/family, and
- man-hours/manufactured piece/family.

The foregoing describes the feedback needed for both work load forecasting and for monitoring productivity, i.e., matters of shop operations. However, man-hours/manufactured weight/family, which is an average, times the weight of each pipe piece of that family yields an estimate of man-hours/pipe piece. The summation of all such estimates by system is an estimate of fabrication man-hours/system which is feedback for estimators.

Obviously, because of the large number of pipe pieces usually involved, derivations and applications of productivity indicators require computer-processing capabilities. This is another example of why competitive shipbuilders regard computer-aided material definition as their most important computer application.







Straight  $E_S = e_1 + e_2 + e_6 + e_7$   
 Straight/Branch  $E_{SB} = e_1 + e_2 + e_4 + e_5 + e_6 + e_7 + e_8$   
 Bent After Fab.  $E_{BAF} = e_1 + e_2 + e_3 + e_5 + e_6 + e_7$   
 Bent Before Fab.  $E_{BBF} = e_1 + e_3 + e_4 + e_5 + e_6 + e_7$   
 Assembled  $E_A = e_1 + e_4 + e_5 + e_6 + e_7 + e_8^*$

when  $E$  = productivity index/family  
 $e$  = productivity index/work station

\* if branch is included

Figure 2-15: Man-hours/manufactured weight/family is obtained by summing the pertinent productivity indices for each work station (stage) as shown. Man-hours/manufactured piece/family is obtained the same way.

## 3.0 SUGGESTIONS

### 3.1 Prerequisites

*The* key to improving pipe-shop productivity is to provide services which allow workers to concentrate on their prescribed work, e.g., marking, cutting, welding, etc., without their being disturbed by unforeseen events. This calls for extraordinary planning and scheduling by the pipe shop, manager particularly when determining a lot size per week. Further, PPFM is dependent upon extraordinary consideration of pipe-shop fabrication problems by people charged with design, material definition, and material control.

### 3.2 Statistical Control

Continuous improvements in pipe-shop work processes should be derived from statistical analysis similar to that practiced by competitive shipbuilders.<sup>7</sup> Standard ranges and tolerance limits based on normal performances are needed for such matters as straightness, overall length, alignment of flanges and orientation of flange bolt-holes. Further, competitive shipbuilders establish standard ranges and tolerance limits for pipe-pieces that are consistent with those for pipe supports and for flatness of decks. This permits them to land and weld even large outfit units without having to mark and cut supports to fit deck undulations.

### 3.3 Facilities

PPFM is a logic for organizing work regardless of whether a shop is manually or automatically operated. Group Technology (GT) applied and fully exploited as PPFM is necessary to determine if additional facilities are required. That is, it is impossible to tell if new facilities are really needed without having first achieved controlled work processes.

Just before the Arab "oil shock" of 1973 depressed the shipbuilding market, significant investments were made by shipbuilders abroad to completely automate functions such as cutting, flange mounting, welding and bending. Even automated auxiliary equipment was installed for raw-pipe storage and issue, intermediate buffer storage and for machine-to-machine transfer. The work instructions used to control such machines are combined by computer with planning and scheduling data.

In planning such installations it is normal to evaluate economical aspects only in consideration of an expected pipe-shop fabrication work load. Equally important and often overlooked, is the need to simultaneously address what is required to design pipe pieces and define required materials in form and number suitable for computerization to support zone outfitting. Equally important and often overlooked, is what is required to provide materials organized so as to best obtain the benefits of automation. In other words, a pipe-piece fabrication system includes design, material definition and material control through palletizing. No aspect of the system should be considered for improvement without evaluating its impact throughout the whole system.

### 3.4 Positioning Automated Devices

Special consideration is given the position of automated devices. Positioning a device at the end of a flow line may reduce work-in-process. Placing an automated device at the beginning of a line might actually increase work-in-process, thereby increasing costs.

### 3.5 Straight Pipe

Straight pipe represents the largest of pipe piece families and requires the least fabrication time. It is naturally adaptable to jigs and devices which can significantly improve productivity. Straight pipe is the easiest to transfer from stage to stage. The production line for straight pipe should be arranged so as to provide minimum travel distance between material entrance and product exit.

### 3.6 Branches

Branches belong either to the straight family or assembled family. As shown in Figure 2-15, a separate flow lane for branch pieces feeds regular work flows at branch fitting and assembling stages. A branch-only flow lane is usually controlled by a cutting list which regulates the disposition of remnants.

### 3.7 Cold Bending

For other than straight pipe pieces, pipe-shop productivity is dependent on the design department adopting principles which allow cold bending to the maximum extent. Fitting work is usually tripled when assembled pipe is substituted for pieces that could be cold bent.

When organizing cutting lists, pipe pieces within a lot should be grouped together by size, wall thickness and bending radius to minimize die changes.

### 3.8 Design

Composites, both in transition design and work instruction (detail) design, are prepared in the context of a preconceived pallet list derived from a previous similar arrangement, i.e., a list of proposed work packages categorized by zone/problem area/stage. As the design develops, the pallet list is refined usually by making adjustments in zone boundaries only. Sometimes, the developing design justifies splitting a work package into two or combining two into one. A change in stage is also possible.

Finalizing a pallet list as soon as possible is important because it determines the sequence that MLP are prepared. That is, designers prepare pipe-piece details in a sequence dictated by pallet requirements. Thus, they continuously have to shift from system to system and use the composite prepared in transition design for check off purposes.

The composite prepared during work instruction design is used to prepare work instructions for individual pipe pieces, MLP. Once the coordinates for pipe-piece end points and bend intersection and other critical points are defined, all remaining functions follow a pattern which requires much computation. This non-creative phase is more quickly and more accurately performed by computer. The computer produces specific dimensions, exactly defined material, welding, coating and palletizing information as required for pipe-shop operation. The computer provides pipe-piece family classification, weight and data needed for planning and scheduling which is derived from normal rates for man-hours, progress and productivity per pipe-piece family.

Obviously, a computer can only fulfill a pipe-shop manager's complete needs when such feedback as fabrication period, man-hours required and fabrication procedure per pipe-piece family are based on immediate past, *normal* pipe-shop performances.

### 3.9 Computer Scheduling and Leveling

Use of a computer is natural for calculating man-hours required to produce each pipe piece based on master-file data for controlled work processes. The computer derives the date on which fabrication must start for each pipe piece: start date equals pallet assembly date minus the normal lead time for a specific pipe piece family. As shown in Figure 1-21, different pipe pieces can have different start-fabrication dates in order to meet a common pallet date.

The computer first calculates for each pipe-piece family and for each flow lane, the man-hours required for cutting, bending, welding, assembling and finishing stages. Sometimes work is heavily concentrated at one stage, e.g., a welding station. Then, the computer schedules pipe pieces with large welding requirements, earlier but within the limits of normal lead times.

Such leveling by computer is not possible without feedback which reflects a pipe shop's latest normal performances. Moreover, large amounts of last minute requirements such as for owner changes or repair work, requires that peak leveling be performed manually.

### 3.10 Lot Size

In planning pipe-piece fabrication (work-load scheduling, material control scheme, etc.) a planning cycle of one week is usually most practical. A rough lot size considered in overall scheduling then corresponds to the work volume for one week's production. As the total work volume that can be handled in one week is constant, the amount of pipe pieces that can be produced during one week depends on the complexity of fabrication work required.

The distribution of work imposed by a lot does not normally match the distribution of available shop capacity for bending, assembling, welding, etc. Apart from watching to see that overall work volume does not greatly exceed total shop capacity, more detailed work scheduling is required to level work-load peaks for certain work stages. For this reason, detailed work schedules drawn up by individual operators covering say half a day's work at most, are useful for determining the actual work load for each workstation.

Leveling such peaks is conditioned on a certain amount of flexibility. Operators have to be capable of undertaking jobs in more than one work station.

### 3.11 Material Transfer and Storage

Pipe-shop work should flow in a single direction. That is, there should be no disruptive reverse flow. Since the time at each work process is relatively short, a correspondingly high throughput of work pieces is necessary to fully utilize available machinery. Therefore, sufficient means of conveying and handling incoming material and outgoing products must be considered. The distance traveled by each work piece between stages should be minimized. Transfer between stages could be accomplished by a number of alternatives. The most productive approach is to have the work piece delivered by the team completing the preceding stage.

Consideration of in-process storage for work pieces between stages is an important factor. While excessive floor space should not be reserved for such storage, means should be devised for this purpose. One such device is storage in tiers to maximize floor space utilization. Whatever medium is devised, intermediate storage should be capable of buffering materials for one half to one work day.

Space and handling facilities for stock pipe should anticipate one week's operation. However, large diameter pipe which requires excessive space should be limited to two to three day's stock depending on anticipated volume.

### 3.12 *Special Work*

Regardless of the effectiveness of PPFM, some separate facility should exist for special work which would otherwise disrupt regular work flows. Special work includes some owner changes at the last minute and ship repair work.

### 3.13 *Progress Control*

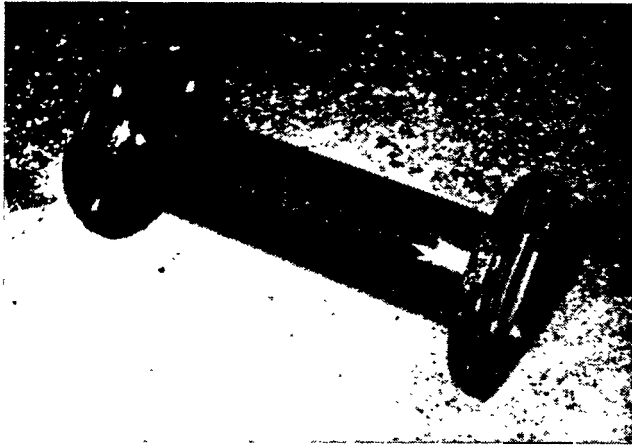
As shown in Figure 2-5, the main responsibility for work-progress control is assigned to a Planning and Control Group and to a Palletizing Group. However, foremen and workers charged with shop operations are required to cooperate by such means as pinpointing work behind schedule and sorting pipe pieces emerging from the finishing stage according to surface treatment required at the next stage.

### 3.14 *Control of Subsidiary Materials*

Welding rods, adhesives and other such materials required in a pipe shop are freely available to workers. Book-keeping to cover consumption is linked to associated items such as flanges in order to assign costs to specific ship construction projects.

### 3.15 *Pertinent Photographs*

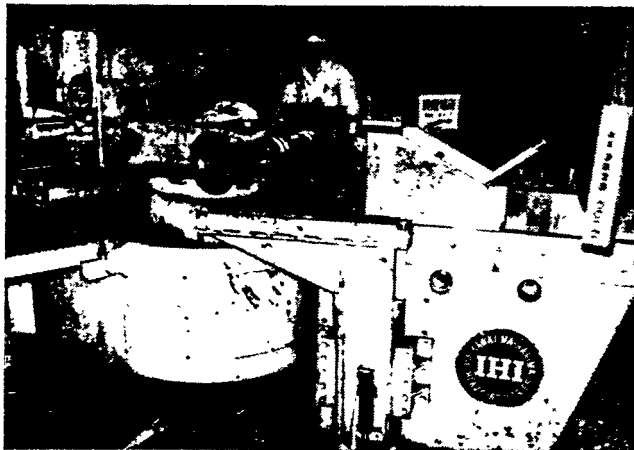
Figures 3-1 through 34 illustrate various aspects of PPFM in operation.



A



B



C

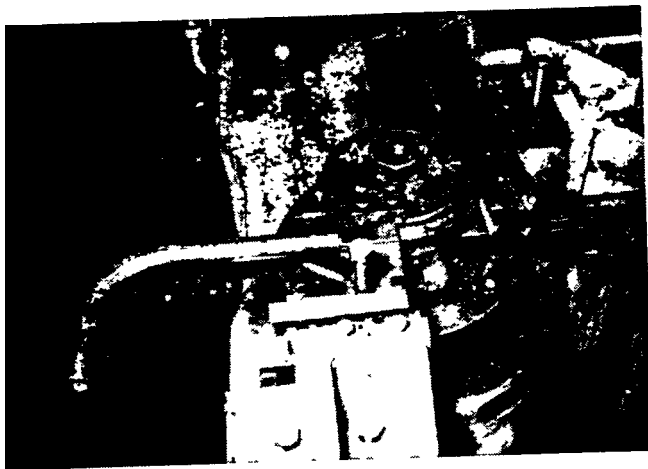


D

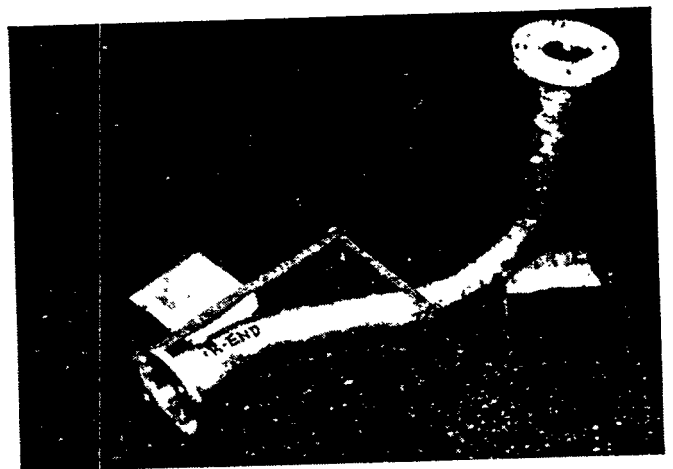


E

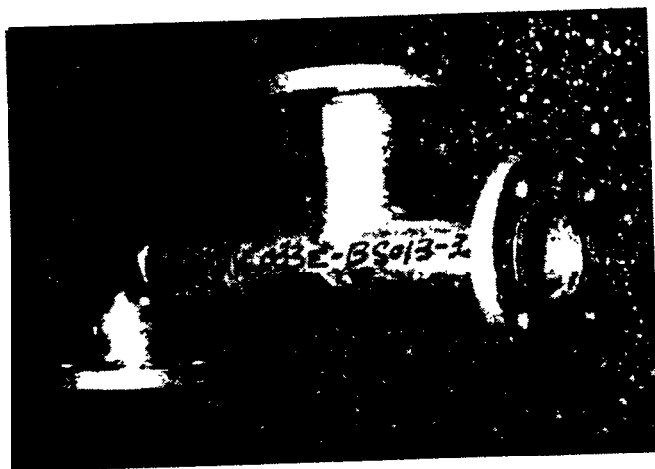
*Figure 3-1: Typical PPFM Classifications.*  
A & B. Straight.  
C, D & E. Bent after fabrication.



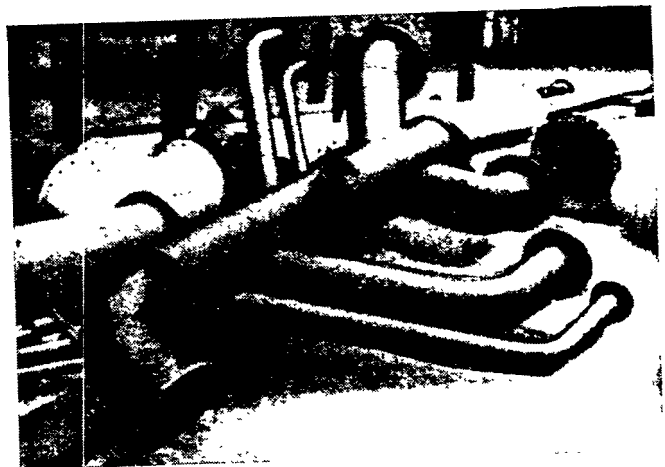
A



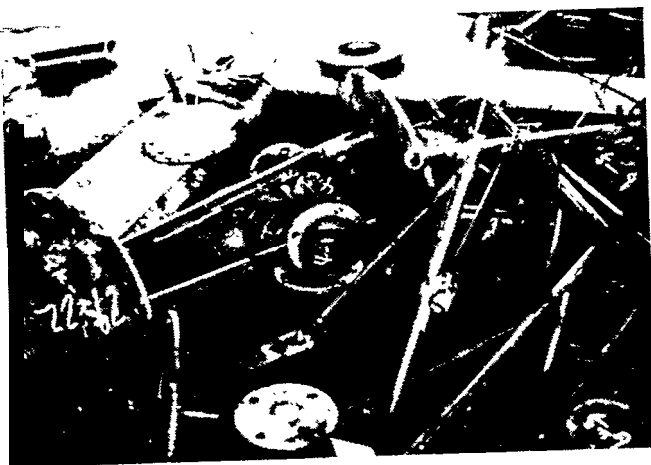
B



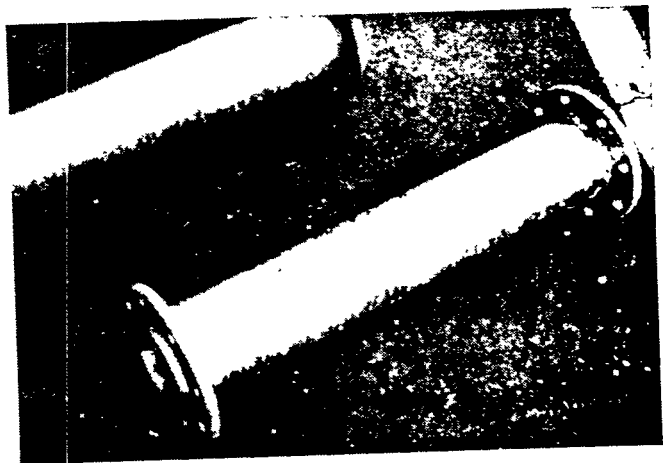
C



D



E



F

*figure 3-2: Typical PPFM Classification*

A & B. Bent before fabrication.

C. Assembled.

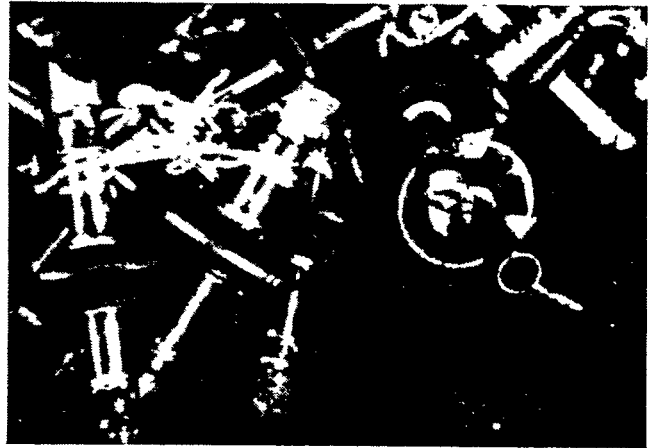
D. Unit Assembled.

E. Mocks for molded.

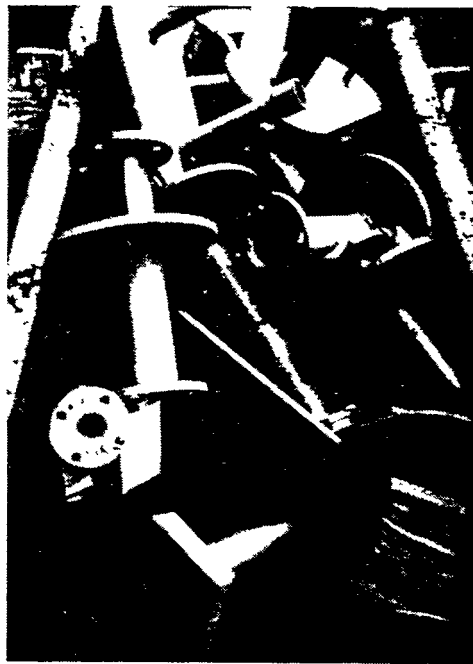
F. Adjusted (loose flange).



A



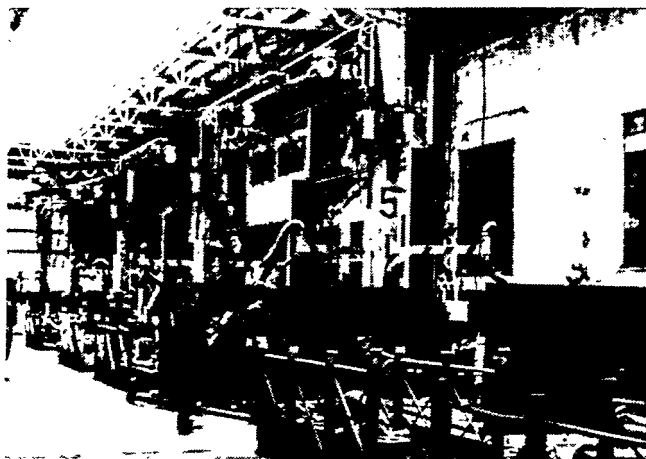
B



C

*Figure 3-3: Typical PPFM Classifications-Penetrations.*

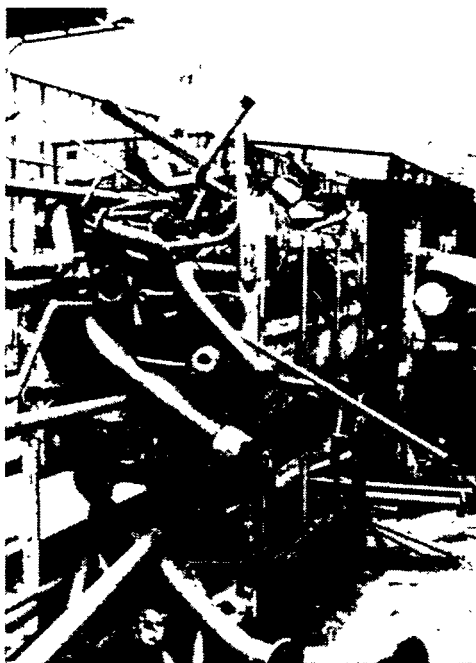
- A. Parallel pipe runs facilitate a single penetration assembly for more than one system.
- B. Copper tubing brazed to steel for penetrations.
- C. Completed penetrations for various systems including hydraulic-oil systems.



A



B



C



D

Figure 3-3: Miscellaneous.

- A. Workstations for assembled pipe pieces are aligned in a row between two lanes wide enough for forklift access. The containers in the foreground are for completed pipe pieces. Similar containers in the lane not visible are for kits of material. Work is organized and controlled through control of material (Italcantieri, Monfalcone).
- B. Many pipe-pieces do not require special coating facilities. Thus, they are productively painted by hand just before palletizing.
- C. Containers of palletized pipe pieces can be tiered to save stowage area.
- D. Lanes between buildings can be used as palletizing areas.



## APPENDIX A

LEVEL	<div>PIPE PIECE JOINING</div> <div>PIPE PIECE ASSEMBLY</div> <div>PIPE FABRICATION</div>					
AREA	MATERIAL	X-RAY OR NIL	MAIN OR BRANCH	BORE	STRAIGHT OR BENT	LENGTH
SUB-AREA	STEEL	NIL	MAIN	SMALL	STRAIGHT	
					BENT	
				MEDIUM	STRAIGHT	SHORT
					BENT*	LONG**
				LARGE	STRAIGHT	SHORT
					BENT*	LONG**
			BRANCH			
		X-RAY				
		NONFERROUS				
		PVC				
	OTHER					

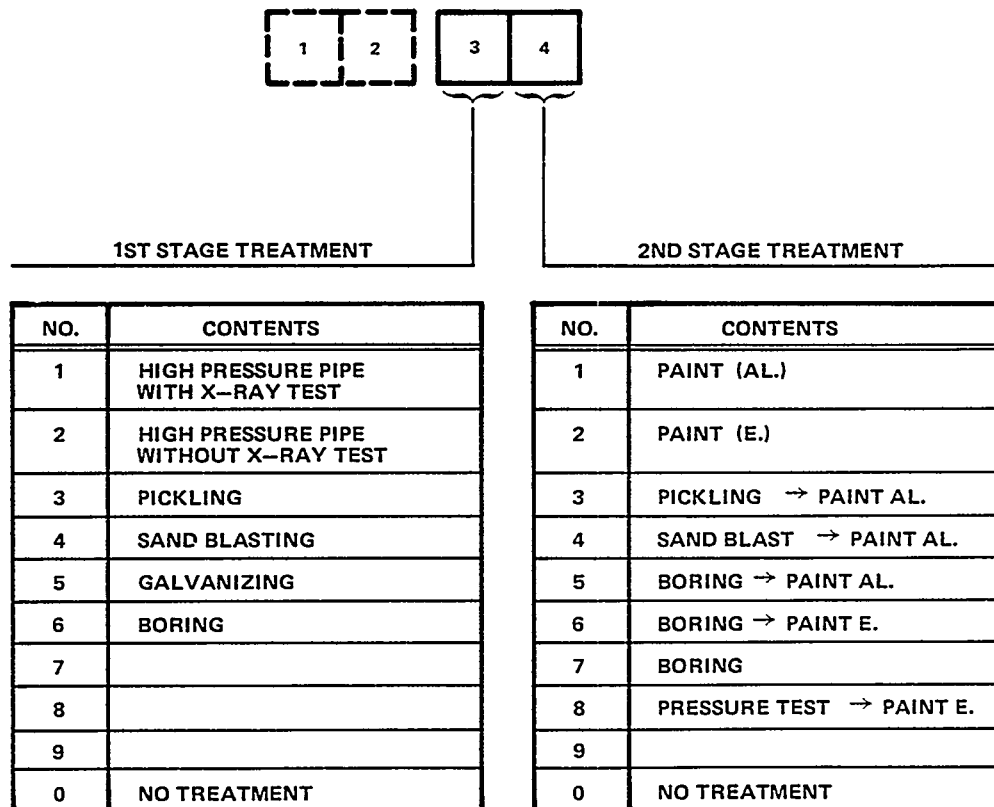
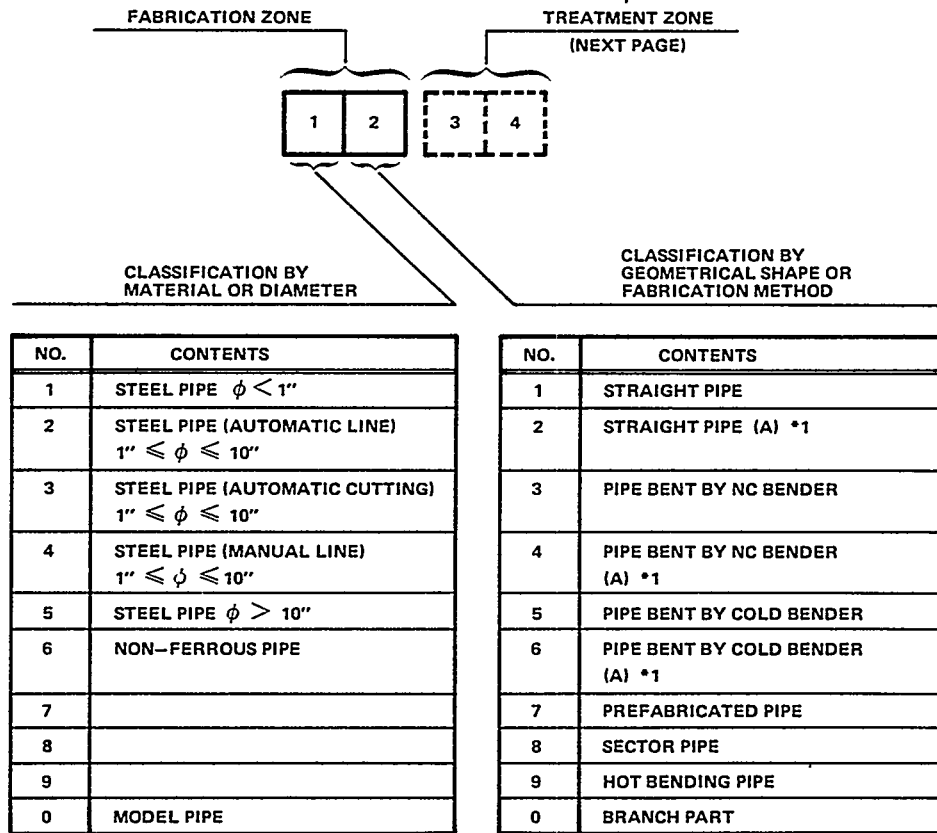
Problem *Area* subdivisions for Pipe Fabrication, Pipe Piece Assembly, and Pipe Piece Joining Levels only. Blank spaces indicate that no further subdivision exists. \*Medium and large bore pipe pieces to be bent can be assigned the same *area* subdivision. \*\*Similarly, long, medium and large bore pipe pieces can be assigned the same *area* subdivision.

TYPICAL CLASSIFICATIONS FOR PIPE-PIECE FAMILY MANUFACTURING (PPFM)		
PPFM NO.	PIPE PIECE CLASSIFICATIONS	SKETCH OR REMARKS
01	Straight $\leq 50$ mm	
04	$\leq 200$ mm	
07	$\geq 250$ mm	
11	Bent After Fabrication $\leq 50$ mm	
14	$65 \sim 200$ mm	
21	Radiographic Tested (Total Insp.)	
24	(Sampling Insp.)	
25	Hydrostatic Tested $\geq 40$ kg/cm <sup>2</sup>	
27	$< 40$ kg/cm <sup>2</sup>	
31	Plastic	
34	Bent By Heating	
41	Bent Before Fabrication $\leq 50$ mm	
44	$65 \sim 200$ mm	
51	Assembled $\leq 50$ mm	
54	$\leq 200$ mm	
57	$\geq 250$ mm	
61	Special Coating - Lining	
69	- Galvanizing	
71	Threaded	
77	Penetrations	
81	Heating Coils	
84	Stainless Steel	
87	Non-ferrous	
90	Urgent (M)*	
91	Molded and adjusted	
92		
93	Aluminum brass pipes (M)	
95	Unit Assembled	
96	Long-term** (M) - Equivalent to PPFM No. 21, 24, 27 & 61	
97	Cast Steel	
99	General (M) - Except for PPFM No. 96	
00	Molded and adjusted (M)	

\* (M) designates manually prepared pipe-piece drawings.  
 \*\* Requires longer than average time.

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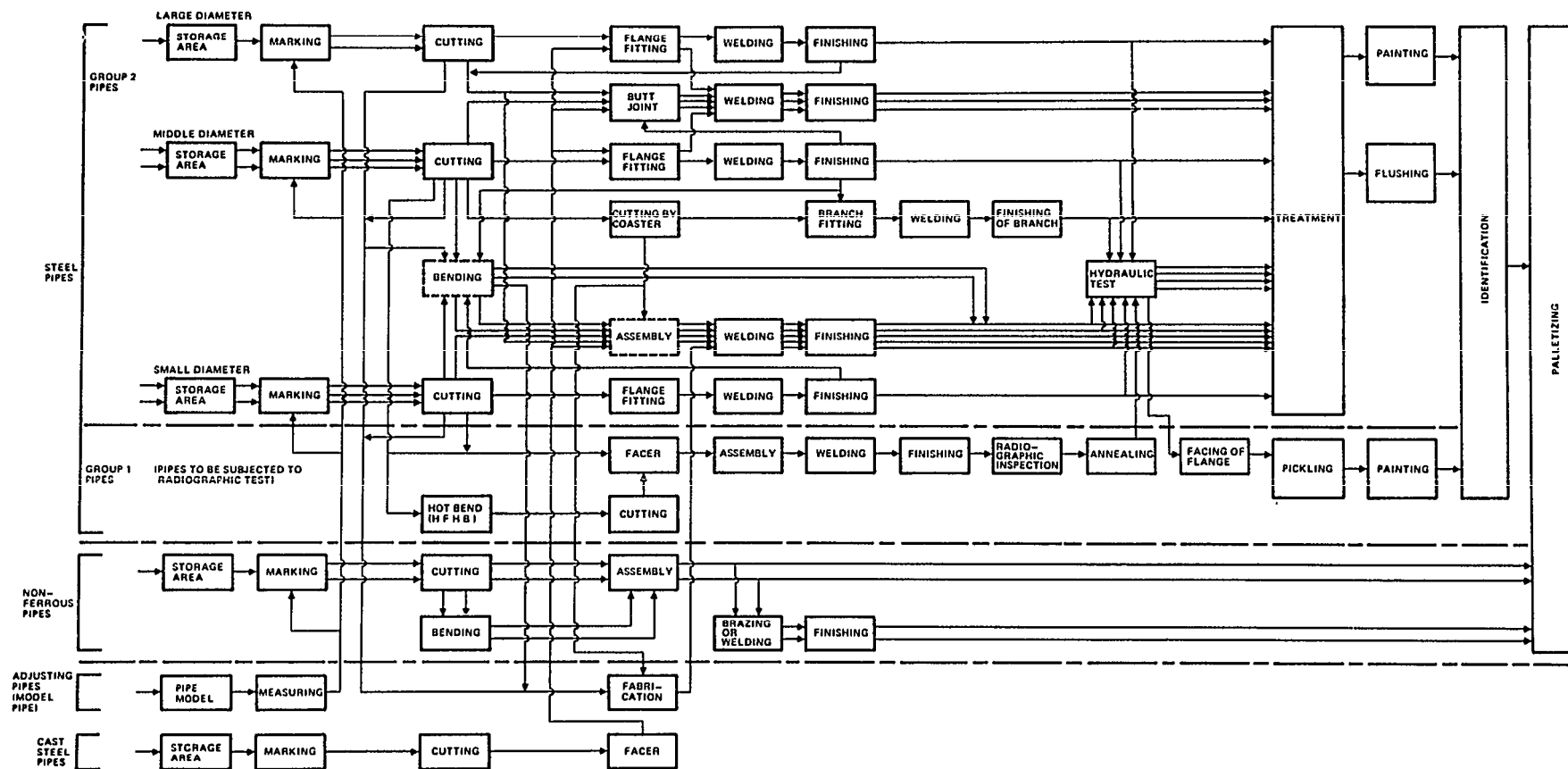


Example of codes for Pipe Piece Family Manufacturing (PPFM).

## MANUFACTURING SYSTEM

MANUFACTURING SYSTEM										After-Treatment System																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
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Low Pressure Pipes in General	Galvanized Pipes	20ϕ & below	Straight Pipes	ON-LINE	F 0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																

Typical decision logic table for use by designers to determine pipe-piece families. The table can be applied in computer aided design systems to automatically generate pipe-piece family identifiers. This table was developed for a pipe-fabrication shop in a European shipyard which features an automated production line in addition to manual work stations, hence the terms "on-line", "off-line".



Pipe fabrication flow in a manual pipe-shop which employs PPFM.

## APPENDIX C

### Middle Term Load Scheme

Line No.:				Date										Page	
Week	Ship No.	MLF No.	P.P. Family	P.P. Q'ty	Cutting date	Cutting time	Bending date	Bending time	Fitting date	Fitting time	Welding date	Welding time	Grinding date	Grinding time	Total time

### Weekly Load Input Schedule

Week	3rd/Feb.								4th/Feb.				1st/Mar.				2nd/Mar.			
Dept.	Machinery				Deck				Mach.		Deck		Mach.		Deck		Mach.		Deck	
P.P.	E.D.P.S.		ADD.		E.D.P.S.		ADD.		E.D.P.S.		ADD.		E.D.P.S.		ADD.		E.D.P.S.		ADD.	
Family	Shops	Q'ty	Hr	Q'ty	Hr	Shops	Q'ty	Hr	Q'ty	Hr	Q'ty	Hr	Q'ty	Hr	Q'ty	Hr	Q'ty	Hr	Q'ty	Hr

### Weekly Load Input Schedule

Week		3rd/Feb.													
Output Class		M.ADD		M.MANU		D.ADD		D.MANU		M.EDPS		M.EDPS		Total	
Shops		Quantity	Q'ty	Quantity	Q'ty	Quantity	Q'ty	Quantity	Q'ty	Quantity	Q'ty	Quantity	Q'ty	Quantity	Q'ty

### Subcontracting Expense Calculation

Date:

TOTAL

### Branch Pipe List

## MLF Organized to Facilitate Palletizing

Pallet Required Date:

	Line No.
	Ordering No.
	Fitting, Welding Condition, Shape
	Diameter, Quality
	Length
	P.P. No.
	Assembly Date
	Completion Date
	Weight
	Paint
	Pallet Date
	Family
	Inner Surface Area
	System



### Pipe-piece Surface Treatment Scheme

Treat. Code	Ship No.	Finish. Week	Inside Area	Outside Area	P.P. Q'ty	P.P. Weight

### Pipe Piece Coating Scheme

Ship No.:		Week:				
Coating Code	Inside Area	Outside Area	P.P. Q'ty	P.P. Weight		

### Group I Pipe-piece List

Ordering No.	Ship No.	MLF No.	P.P. No.	Pipe dia.	Testing pressure	Coating	Weight	P.P. family	Comments	Class of ship	Sign for loose flange	Inside area of P.P.

## Material Issue Order

Material Control		Store	
Outfit Material Code			
Description (Quality, Standard, Size, Comment)			
Painting			
Ship No.			
Order No.			
Repeat			
Unit of			
P.P. Family			
Part No./Dwg. No.		Deliver Date	
Designer			
Deposit			
Group			
Qty of Pipe			
Rack No.			
Remarks			